

# TOPICS OF THE MONTH

## **Chemical engineering research probe widens its scope**

**C**HEMICAL firms have responded well to a detailed questionnaire asking for practical details of the operation of industrial-scale packed columns, according to the annual report of the Association of British Chemical Manufacturers. Eleven firms have indicated their willingness to collaborate with the Manchester College of Advanced Technology, who are working on this subject.

The questionnaire followed the report of the Distillation Panel set up by the A.B.C.M. and the British Chemical Plant Manufacturers' Association, in which six projects were recommended as suitable subjects for basic research by universities under the sponsorship of the two associations (see *CHEMICAL & PROCESS ENGINEERING*, 1959, 40 (6), 211).

A further questionnaire is being circulated to see what the chemical industry wants done about the subject of liquid/solid separation, which is being considered by another panel. The possibility of setting up specialist panels in further fields is also being considered. Gas cleaning was the subject of a questionnaire circulated recently and the response has revealed substantial interest in this subject.

Amongst other topics discussed in the A.B.C.M. annual report is the painful one of delayed chemical plant deliveries. This subject has been raised at various committee meetings and in discussions with the B.C.P.M.A. and one of the latest developments is a move to get chemical plant deliveries speeded up through increased standardisation. Further information on deliveries is still being collected and it is early yet to say whether there has been any improvement since the subject was first raised.

## **Elements of uncertainty**

**T**HE development of fuel elements of high integrity and long burn-up is an important problem to be solved before economical nuclear power can be achieved. In his introductory address to the European Atomic Energy Society symposium in Stockholm on October 5, Sir John Cockcroft drew attention to some outstanding problems, such as the overcoming of defects in manufacture and handling which lead to leaky welds—a matter for the fabricator and inspector—and growth phenomena in 'cold' fuel elements leading to strain of the cans and subsequent development of slow leaks. The growth phenomena call for an understanding of residual preferred orientation in uranium and uranium alloys and also cavitation phenomena in canning materials. These are fields for the classical metallurgist.

The future of fuel elements seems likely to lie in the ceramic field as temperatures increase and, Sir John points out, a better understanding is needed of how

fission products, particularly the fission gases, are held in ceramics, and what the conditions are which lead to migration and release to build up internal can pressures. Thermal cycling and its effects on the cans, particularly when these are thin-walled, is another problem.

As well as the effects of irradiation fissile materials, there is a need to worry about its effects on beryllium if this is used for cans and on beryllia (beryllium oxide) when it is used for moderators or as a fuel diluent in high-temperature reactors. The effects of irradiation on the steels of pressure vessels must also be considered and it must be ensured that the increase of the transition temperature due to fast neutron doses is a modest one, so that the steel will at all times be kept above the transition temperature. Steels vary greatly in their characteristics of this kind and, of course, the properties of the welds become of even greater concern.

The problem of energy storage in graphite, and methods of safe annealing of the stored energy, have been the subject of several years' intensive work in the U.K., and the problem is now fairly well understood, but another year's work will be necessary to complete the picture. Thus it has recently been found that, although stored energy ceases to become a problem at high irradiation temperatures, dimensional changes become important and more quantitative information on this subject is required to help the designers.

## **Olefines at Wilton**

**T**HE importance of the new heavy organic chemicals industry in Britain was recognised, first, in the setting up of a Heavy Organic Chemicals Division by I.C.I., and now (as reported on another page) in the formation of a new group within the Society of Chemical Industry to cover this industry's interests. More concrete evidence of the expansion that is taking place in this field is embodied in the recent starting up of I.C.I.'s third olefine plant at Wilton, Yorks., which raises the company's olefine capacity by 60%. Output of the division's chief product, high-purity ethylene, is now about 110,000 tons p.a., and plans are being considered to increase this to perhaps 140,000 tons p.a. The olefine works at Wilton with their associated plants now form the world's largest petrochemical facilities based on liquid feedstock. About 90% of Wilton's ethylene goes to the neighbouring I.C.I. plants for polythene manufacture.

The No. 3 plant uses essentially the same processes as the first two plants but is much larger. There is a pyrolysis section followed by the product separation and purification section. Operating at temperatures from 2,000 to -200°F., the plant is an excellent example of modern chemical engineering. A noteworthy feature

is the battery of free-piston gas generators which drive the turbines for the centrifugal gas compressors extensively used in the plant. Another is the use of a new demethanisation process, whereby methane nearly 100% pure is produced while a costly stage of refrigeration is eliminated.

### Benefits of beneficiation

**B**ENEFICIATION is a term usually associated with the separation of minerals from their ores, but if it is taken to mean a process in which the various properties of the component parts of materials (specific gravity, magnetic susceptibility, surface characteristics, resistance to grinding, etc.) are used to achieve a physical sorting, then the techniques of beneficiation have potential applications in many industries far removed from the production of minerals.

Thus, beneficiation has been used successfully to separate rubber from cord in scrap from tyre manufacture, and silver from waste photographic film. In this latter application, one film manufacturer in the U.S.A. annually recovers silver valued at \$3 million from spoiled or outdated film, trimmings and worn-out cine film.

These examples were given in the September issue of *Battelle Technical Review* by A. L. Wesner, who lists 28 unusual applications for beneficiation techniques that are in limited use or are feasible. They range from the separation of sewage from water by a flotation process to the electrostatic separation of weeds from seed.

The author urges technical men in non-mineral industries to make a critical examination of their raw materials, intermediate products, final products and all waste products to discover new applications for beneficiation. He feels that there are opportunities for economical exploitation of these techniques in many industries, which skilled and capable personnel fail to grasp because such techniques are foreign to their experience.

### More triumphs for Ti

**R**EPORTS on the successful use of titanium in industrial plants come in fairly frequently these days, especially from the U.S.A. The latest is concerned with the use of a titanium-clad pressure vessel in a Californian petrochemical plant. Built early this year, the vessel is said to have withstood many months of strenuous service.

The vessel was designed for a working pressure of 150 p.s.i. at 500°F. and measures about 4 ft. in diameter by 12 ft. high, being fabricated from plates of  $\frac{1}{2}$ -in. mild steel clad with  $\frac{5}{16}$ -in. and  $\frac{3}{4}$ -in. grade A-40 titanium. Hemispherical heads, top and bottom, were each welded from pressed segments. Fittings and flanges were titanium-lined. Research and development work carried out by Chicago Bridge & Iron Co., who built the vessel, included the design and construction of a small titanium-clad vessel and its operation for over a year to test the welding techniques. Procedures were developed to prevent contamination

of the titanium cladding by the steel backing plate, forming problems were solved, and ways were found to vacuum-clad in titanium at sheet sizes comparable to sheets of conventional corrosion-resisting metals. Clad sheets up to 5 ft. by 7 ft. were used on the first vessel.

Crucible Steel Co. of America recently reported an extensive evaluation of various corrosion-resisting metals to see which would resist attack in a catalytic reformer (regeneration gas scrubber) which is subjected to highly variable temperature and gas composition. The corrosive media, at a pressure of 300 p.s.i. and ranging in temperature from 100 to 500°F., contain CO<sub>2</sub>, O<sub>2</sub>, H<sub>2</sub>O and traces of SO<sub>2</sub>, Cl and NH<sub>3</sub>. Test spools of various metals, including titanium, were placed in four locations in the tower and removed two months and 1,368 stream hours later. According to Crucible Steel, titanium was the only metal with no visible signs of corrosion; it was also the only metal that was consistent in resisting attack regardless of its location within the unit. The company feels that, on the basis of these tests, titanium has a promising future in the petroleum industry.

### An 'Argonaut' in Germany

**T**HE experimental nuclear reactor recently brought into operation at Garching, near Munich, by Siemens-Schuckertwerke A.G. has the distinction of being the first reactor constructed in Germany and consisting entirely of components made in Germany, only the fuel (enriched uranium oxide) being obtained from the U.S.A. The reactor is modelled after the *Argonaut* reactor at Argonne University and is exclusively destined for research and testing purposes. It is capable of giving a continuous output of 1 kw. which can be increased to a short-time maximum output of 10 kw.

The use of unit construction methods and the variety of ways in which the fuel elements can be arranged makes this reactor well suited to experimental purposes. The fuel elements are housed in the interstice between two co-axial aluminium cylinders and are placed in water, together with graphite blocks which serve to retard the neutrons released by the nuclear fission. Inside the cylindrical containers is a graphite cylinder which serves as internal reflector and is provided with channels to accommodate samples of material or measuring instruments. On the outside, the reactor core is likewise shielded by a graphite reflector, and by a great number of concrete blocks. The safety devices are wholly automatic and are regarded as foolproof.

This type of reactor, though comparatively inexpensive, is also well suited for training purposes and for the preparation of radioactive isotopes. Siemens-Schuckert have decided to include such reactors in their normal production programme for the benefit of universities, technical colleges and research institutes.

The installations at Garching comprise, in addition to the reactor, a number of laboratories and ancillary premises.

### Scientific staff—a new source

COMPETITION among employers for science graduates is as strong as ever, as is proved by the large sums now being spent on advertisements in newspapers and technical journals. To the cost of advertising must be added the expense of management consultants and others whose services are being used to help satisfy the often desperate need for scientific and technological recruits of graduate status.

A far less expensive way of solving this problem has been put forward by Mr. Leonard Hill, chairman of the Leonard Hill Technical Group of periodicals, reference books and textbooks. After careful study of the situation, based on his long experience as a technical and industrial publisher, he proposes a new system which takes advantage of the fact that most students seek temporary employment during the university vacations.

It is proposed that science students should work temporarily for firms of the type which would offer them jobs after they have graduated. This would enable students to become acquainted with industries in which they propose to make careers and, conversely, would enable firms to assess the potentialities of young men and women whom they may wish to employ after they have obtained their degrees. Both sides stand to benefit enormously from this scheme of selective vacation employment and because there are such strong mutual advantages it should work well.

How will it work? Mr. Hill has established the ISIS Appointments Register at 7-9 Eden Street, London, N.W.1. Science students will be invited to apply for registration and firms requiring temporary staff will be invited to submit details of the jobs they can offer. In this way ISIS will bring together employers and employees in an economical and efficient manner. A further saving to employers will be the elimination of extra work caused by the employment of temporary workers. This will be done by employers paying ISIS, who will in turn pay the students and deal with all income tax and insurance details. In effect, the students will be employed by ISIS.

During the period of temporary employment firms will be expected to give students work commensurate with their abilities, with the knowledge that the way in which the students are treated will naturally influence their choice of future career and employer. Most students will cheerfully undertake most jobs, provided they are intelligently and sympathetically handled and are given proper opportunities to assess the career possibilities offered.

Thus, ISIS Appointments Register will bring together employers and future employees for a valuable preliminary period. The use that is made of this period depends upon the good sense of each side.

Employers who require further details of this service should communicate immediately with ISIS Appointments Register, 7-9 Eden Street, London, N.W.1 (Telephone: Euston 5911). Registration of employers' requirements for the Christmas vacation has already begun.

### Benzole refining up to date

THE latest trends in benzole refining are exemplified in a new refinery at Scunthorpe, Lincs., operated by the Lincolnshire Chemical Co. Ltd., which produces pure benzene and other products from crude benzole derived from the coke ovens of the steelworks at John Lysaght's Scunthorpe Works Ltd. With a rated throughput of some 4½ million gal. p.a. of crude benzole, of which 60% is converted to pure benzene, the plant has already achieved production figures far in excess of designed capacity and has been run at an annual rate of nearly 7½ million gal.

The new refinery, replacing an older one on an adjacent site, employs continuous distillation in conjunction with batch acid-washing. The 'defronting' section, which removes the forerunnings and splits the benzole into a light and a heavy fraction, uses a novel system in which the benzole vapours are brought into direct contact with water maintained at a constant temperature. Thus, only the desired forerunnings are taken off and the carbon disulphide content is normally brought down to 0.0002%. The light benzole fraction goes direct to the acid-washing plant and thence to the blow-over still to produce pure benzene. The heavy benzole is distilled to yield toluol, xylol and unsaturated naphtha, these fractions being processed to produce various refined products.

Demand for pure benzene in Britain has increased from 5 million gal. in 1949 to some 38 million gal. in 1959. Lincolnshire Chemical report a similar trend, with a production of 60% of crude to pure benzene in 1959 compared with 5% in 1949, with a corresponding smaller production of motor benzole.

Further interesting developments can be expected in this field, and Lincolnshire Chemical are involved in a new venture, in conjunction with the Steel Co. of Wales, in setting up the Port Talbot Chemical Co. Ltd. to treat the coke-oven crude benzole available at Port Talbot. This new plant would be the first *Hydro-refining* plant in the country to produce pure benzene.

### Counting the cost in engineering

WHEN a contact sulphuric acid plant has to be designed and constructed, the data are so well known that some engineering companies can literally take most of the drawings from the drawer, but for processes where previous knowledge is slight the normal engineering cost can be multiplied considerably. (For the concentration of Uranium 235, for example, three different processes were designed, engineered and constructed simultaneously to ensure that at least one of them would operate successfully.) In fact, a well-defined process can reduce engineering costs by as much as 30% while a poorly defined one can increase them by 50%.

How can the cost of engineering be estimated as a percentage of the estimated capital cost? According to E. R. Sweet, who presented a paper to a symposium on plant costs and economics organised by the American Chemical Society, in Boston, Mass. (*Ind. & Engg. Chem.*, 1959, 51 (9), 991), the base cost of



engineering for an average job will be about 8%, which can be multiplied by a series of percentages, each percentage being a quantitative measure of a number of different factors. The resulting figure is a rough estimate of the cost of engineering expressed as a percentage of construction cost including engineering.

As well as the state of knowledge of the process, factors to be considered include the complexity of the process, for simple processes can decrease costs by 20% while complicated processes can increase them by 40% or even more. The capacity of a plant is not so important as a factor in assessing engineering cost since, within limits, the engineering cost is roughly constant for plants of varying capacities. Materials of construction, however, have a significant effect on engineering cost, according to the proportion in which different materials, *e.g.* mild steel and alloy steel, are used. Another cost factor is the multitude of problems involved in expanding or revamping a plant in an existing facility—depending on the extent of these problems the cost of engineering may be increased by as much as 25% over a 'grass roots' project.

Mr. Sweet concludes that the evaluation of these tangible factors is not quite mechanical, but that an experienced engineer with good judgment can be quite accurate in assigning quantitative effects to each of them.

### **New light on embrittlement**

**W**HY many metals become brittle and crack apart under stress is a vexing industrial problem and the phenomenon has frequently been ascribed to mechanical defects such as the presence of pores, micro-cracks, fissures, intergranular holes, etc. A group of research workers at the Argonne National Laboratory, U.S.A., however, thinks embrittlement of metals is more likely to be due to the directional nature of the bonds formed by atoms of hydrogen. They have found that hydrogen will penetrate metals left exposed to the air for long periods of time and, once inside, the hydrogen atoms form bonds with the larger metallic atoms. This bonding occurs because the orbital electrons of the respective atoms overlap each other and share the nuclei of two or more atoms. As nuclei share common atoms, they share a common bond.

It was observed that the bonds are not formed equally in all directions within the structure of a metal and do not have equal strength. Hydrogen 'pulls' metal atoms away from their neighbours, changing the original structure of the metal. Since some of the bonds are stronger in one direction than another, metal has a tendency to 'break off' when stress is applied along the edge of a bond.

It has long been suspected that the presence of hydrogen was one of the causes of embrittlement. Previously, hydrogen was difficult to detect in metals because adequate research techniques were not available. Now, however, by the use of techniques such as neutron diffraction, the relative positions of hydrogen

and metal atoms within the sample can be detected, while a further refinement of the technique permits detection of hydrogen atoms only within the metal.

### **Civil engineering at Hinkley**

**M**ORE than one author in this issue, contributing to our feature on the planning and erection of chemical projects, stresses the need for good co-ordination between the chemical, mechanical, civil, electrical and other engineers involved. This need is no less evident in the building of nuclear power stations; indeed, the limited amount of previous experience on which to draw, and the novelty of the designs involved, poses some tricky problems of construction, and makes it even more essential for the various phases of the project to be exactly timed.

Our associate journal, *Public Works & Muck Shifter*, which has been running a series of articles on the civil engineering of nuclear power stations, dealt in its September issue with the Hinkley Point project, and remarks on the careful dovetailing of the civil, mechanical and electrical work at this site. At Hinkley Point, a new sea wall, 3,500 ft. long, had to be built to reclaim a 250-ft.-wide strip of foreshore for the site, and more than half of this had to be completed before construction of the turbine house and cooling water system, with its associated pumphouse and tunnels, could begin. Floodlighting made it possible to work round the clock on the sea wall, which was completed last year. The pressure vessels are housed in biological shields with 7-ft.-thick reinforced concrete walls of duodecagonal shape, rising over 90 ft. from the reactor foundations and with internal diameters of over 75 ft. An 11-ft.-thick slab of concrete surmounts each shield and each is contained in huge rectangular concrete envelopes about 140 ft. by 100 ft. All this concrete has to be of special density and placed with accuracy.

### **Hemicellulose degradation at high temperatures**

**N**EW evidence to support existing theory as to how cellulose and hemicellulose are degraded by hot alkaline solutions has emerged from recent research in the U.S.A. In this research, carried out at the laboratories of the Buckeye Cellulose Corporation, reaction rate constants were also developed, thus placing the degradation on a quantitative basis. By using these constants, the effect of a given set of processing conditions on the concentration of dissolved hemicellulose can easily be predicted.

Previously, it was known that wood hemicelluloses are destroyed by heating in alkaline solutions such as are used in the pulping of wood in the sulphate process, and in recent years a mechanism was developed for this reaction. The new findings, reported by R. W. Collier at the 136th national meeting of the American Chemical Society in Atlantic City on September 16, should be of special interest to producers of both dissolving and paper pulps. A low hemicellulose level is desired by cellulose users, particularly manufacturers of super-strength viscose tyre cord and cellulose derivatives.



# SODIUM--REACTOR COOLANT

By B. L. Harbourn, B.sc.

(Development and Engineering Group, United Kingdom Atomic Energy Authority)

*After a brief introduction to liquid sodium as a coolant for nuclear reactors, this article discusses the various practical considerations involved in designing sodium-cooled reactor systems.*

THE potential advantages of liquid metals for cooling nuclear reactors have always been fully appreciated and the first reactor cooled by this means (EBR-1) started operation eight years ago. Despite some 15 years' work aimed at utilising the inherent advantages of liquid metals and overcoming their disadvantages, liquid metal technology is still at an empirical stage. Admiral Rickover, U.S.N., sums up the situation when he points out, in his foreword to the 'Liquid Metals Handbook,' that 'in the liquid metals field there is still no substitute for testing.' Much progress has been made since this statement was made, but it still represents the basic philosophy of liquid metal engineering.

It is useful to examine the reasons for the preference so often expressed for sodium over other liquid metals. The primary requirements of a heat-transfer medium are high thermal conductivity, specific heat, and physical and chemical stability at elevated temperatures. It is preferable to use a non-aggressive fluid so that severe limitations are not placed on materials of construction. High-boiling-point fluids do not require pressurised circuits to suppress boiling so that the difficulties associated with heavy pressure vessels and thick-walled pipework are avoided. A low density is desirable in this context to minimise the coolant burden and consequent pipework stresses. In the special case of nuclear coolants, the fluid must have a low-neutron-capture cross-section and should not be subject to transmutations which will impair its primary function.

The low-melting-point metals lithium, sodium, potassium, mercury, lead and bismuth, and the sodium-potassium and lead-bismuth alloys, all have potentialities judged by the above criteria. It is necessary to examine their physical properties in some detail to make a choice.

## Coolant selection

Data on the eight low-melting-point metals and alloys at 450°C. are presented in Table 1. The range of temperatures which may be encountered is of the order of 300 to 600°C.

in a reactor used to raise steam of comparable quality to that raised in a modern, conventionally fired power station.

The use of mercury is precluded for these conditions by its low boiling point. Apart from this, it is undesirable because of its high neutron absorption and its high density.

Lithium must be eliminated because of its high neutron absorption. Under neutron irradiation, the  $\text{Li}^6$  isotope, 7.5% of which is present, is converted to helium and tritium, the latter being a highly toxic radioactive gas.

Lead and bismuth, although having low neutron absorption, have high densities and so require heavy-section pipework to support the coolant load. The melting points of these two metals are high compared with the others in Table 1. This requires extensive circuit heating to fill or restart the reactor after a shut-down. The difficulties raised by high melting points are overcome by the use of the lead-bismuth eutectic alloy, but other difficulties remain.

Sodium, potassium and their alloys combine low melting points, low densities and moderately low neutron absorption with good thermal properties. On physical grounds, therefore, they overcome the disadvantages of the other low-melting-point metals.

It is desirable to substantiate this argument quantitatively. This may be done arbitrarily by evolving a factor incorporating conductivity, specific heat, neutron absorption and density. Such a factor, designated the 'suitability factor' ( $S$ ), shown in Table 1, is calculated from:

$$S = \frac{\text{Thermal conductivity} \times \text{specific heat}}{\text{Neutron absorption cross-section} \times \text{density}}$$

A high value of  $S$  denotes desirable coolant properties, on a physical basis. It has no practical significance except as a guide to making an initial selection. Other points which must be considered, and which may modify the indication given by  $S$ , include melting and boiling points, chemical reactivity, neutron-induced reactions, corrosion behaviour and cost.

On the basis of the suitability factor, sodium appears to be the most desirable liquid-metal coolant for reactor use. Application of the other criteria noted above does little to alter this opinion.

## Usage of sodium

The difficulties of taking advantage of the desirable properties of sodium as a reactor coolant are reflected in the small number of reactors (Table 2) which are operating, under construc-

Table 1. Properties of Liquid Metals at 450°C.

	Melting point, °C.	Boiling point, (1 atm.), °C.	Density, g./c.c.	Thermal conductivity, ccl. cm. sec./°C.	Specific heat, ccl. g.	Thermal neutron absorption cross-section, sq.cm./g.	$S$
Lithium	180	1,315	0.48	0.093	1.0	6.10	0.032
Sodium	97.8	883	0.84	0.167	0.295	0.013	4.4
Potassium	63.6	760	0.74	0.097	0.182	0.030	0.8
Na-K alloy (70—30)	7—40	793	0.82	0.063	0.269	0.018	1.15
Mercury	-38.9	357	—	—	—	1.08	—
Lead	327.4	1,735	10.4	0.040	0.037	0.0006	0.238
Bismuth	271	1,480	9.65	0.038	0.036	0.0001	1.42
Pb-Bi alloy (65—55)	124	1,670	10.12	0.027	0.035	0.0003	0.31

tion, or expected to start shortly. In fact, only three of these reactors are operational. However, derogatory conclusions about the value of sodium should not be drawn on the basis of numbers, without reference to nuclear power development and utilisation programmes.

In the United Kingdom the programme has been dictated by the peculiar need for large quantities of nuclear power at an early date, thus relegating the development of advanced reactor types to a later stage in the programme. The need for successors to the CO<sub>2</sub>-cooled, graphite-moderated reactors of the first round is fully appreciated and the Dounreay fast reactor exemplifies the progress being made in this direction.

In the U.S.A. the need for nuclear power is not imminent, as adequate supplies of thermal fuels exist. Consequently the American approach to nuclear power has been to survey many possibilities by the construction of reactor experiments yielding physics, engineering, operational and cost data from which commercial-scale power stations may be constructed. Three power plants using sodium cooling are at present under construction. The Russian approach has been similar to the American. The stage has been reached where widespread building of power reactors of many types has been commenced. The programme includes two sodium-cooled

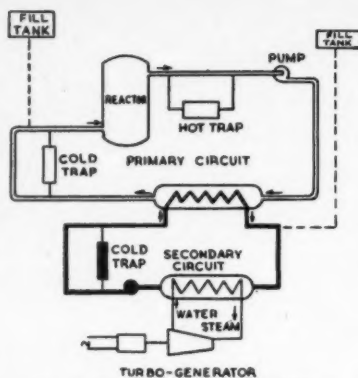


Fig. 1. Schematic coolant system.

fast reactors and probably a sodium-graphite reactor.

It may be concluded that sodium-cooled reactors, although few in number at present, will in a few years' time be making a significant contribution towards the generation of nuclear power.

#### Sodium-cooled reactors

The sodium-cooled reactors in Table 2 fall conveniently into two groups, fast and thermal. In the former no moderator is present to slow down the neutrons, fission being caused by neutrons of about 10<sup>5</sup> ev., whereas in a thermal reactor the neutron energy is reduced to about 0.025 ev. before causing fission.

The difference between reactor

types is significant to the reactor engineer, apart from the obvious requirement of incorporating the moderator in a thermal system. Fast neutrons are less readily absorbed by most constructional materials, so that material selection problems are eased. This energy dependence also applies to U<sup>235</sup>, so that the concentration of fissile atoms must be increased to maintain the chain reaction. Furthermore, in the absence of a moderator the fuel elements are more closely spaced, resulting in much greater heat generation per unit volume than in a thermal reactor. In heat production the S.G.R. and the E.F.A.P.P. reactors are similar (250 Mw.) but, whereas the core of the former is a 14-ft. cylinder, that of the fast reactor is a 30-in. cylinder.

A common feature of both types of reactor is the effect of neutron irradiation of the coolant. A  $\beta$ - $\gamma$  active isotope Na<sup>24</sup> is produced, requiring that all parts of the circuit shall be shielded to protect personnel. Direct coupling of an active sodium circuit to a steam generator raises two possibilities. A heat exchanger failure would result in transport of radioactive material to the turbine house, an unacceptable hazard. There is a possibility that the ionising effect of radiation on water may create ionic species which will accelerate corrosion and eventually cause failure of the heat exchanger. It is believed that this

Table 2. Sodium-cooled Reactors

Name	Location	Type (moderator)	Coolant. Outlet temp. (°C.)	Power		Power density (kw./kg. 235)	Fuel	Operation commenced
				Heat (Mw.)	Elec- trical (Mw.)			
Sodium Reactor Experiment	California, U.S.A.	Thermal (graphite)	Na 515	21	6	240	Uranium (2.8% 235)	April 1957
Sodium Graphite Reactor	Nebraska, U.S.A.	Thermal (graphite)	Na 495	245	75	473	Uranium dioxide	c. 1962
Fast Fission Reactor	Dounreay, Scotland	Fast	NaK 350	60	15	180	Uranium (40% 235)	1959
Experimental Breeder Reactor—1	Idaho, U.S.A.	Fast	NaK 315	1.4	0.2	18	Uranium (90% 235)	Feb. 1951
Experimental Breeder Reactor—2	Idaho, U.S.A.	Fast	Na 482	62.5	20	300	Uranium (45% 235)	Mid-1959
Enrico Fermi Atomic Power Plant	Michigan, U.S.A.	Fast	Na 430	300	100	—	Uranium (25% 235)	1960
Los Alamos Molten Plutonium Reactor Experiment	Los Alamos, U.S.A.	Fast	NaK 315	1.0	—	—	Plutonium (liquid)	1957
	Alaska, U.S.A.	Thermal (D <sub>2</sub> O)	Na 510	40	10	380	Uranium (1.5% 235)	
BP-50	U.S.S.R.	Fast	Na 500	200	50	800	Plutonium or uranium dioxide	

mechanism was in part the cause of the failures of the U.S.S. *Seawolf's* heat exchangers.<sup>1</sup>

The normal practice is to interpose an inactive sodium circuit between the primary coolant and the steam circuit. The primary heat exchanger is shielded against neutrons from the core and from the working areas. A typical circuit configuration is shown diagrammatically in Fig. 1.

It is necessary to protect the graphite moderator from the coolant, as the amount of sodium which would be absorbed would greatly increase neutron losses in the core. There is also the possibility of mechanical damage to the moderator. Thin zirconium jackets are used for protection in the S.R.E., but it is proposed to use stainless steel in S.G.R.

Many features of these reactors, including sodium handling, material selection and behaviour, and circuit component design, are, in general, independent of particular designs and may be discussed as such.

### Sodium handling

Liquid sodium is a powerful reducing agent requiring strict measures to prevent its contact with water, air or other oxidising media. Ingress of a large quantity of oxidant to the circuit could result in a fire or explosion, but the effect of small leaks, although less dramatic, could be equally serious. The corrosive action of sodium on most materials is strongly dependent on its oxygen content, as will be shown later. It is necessary to protect the sodium from oxidation by preventing the ingress of oxygen. Adequate leak tightness cannot be guaranteed on a large and complex circuit, so that some means of oxygen removal must be installed.

Protection of the sodium is achieved, apart from applying the highest possible standards during circuit fabrication, by blanketing it under an inert gas. Free surfaces such as occur in the pool above the reactor or in the filling tanks are usually protected by helium, while the main pipework galleries contain an atmosphere of nitrogen.

It must be assumed that some oxygen will enter the circuit and will require continuous removal. Four methods are available for this purpose. Fresh sodium usually has a high oxygen content, much of which can be removed by passing it through sintered stainless-steel filter plates.

The solubility of oxygen or oxide in sodium decreases with temperature (Fig. 2), so that, by cooling the liquid metal in a suitable vessel, the pre-

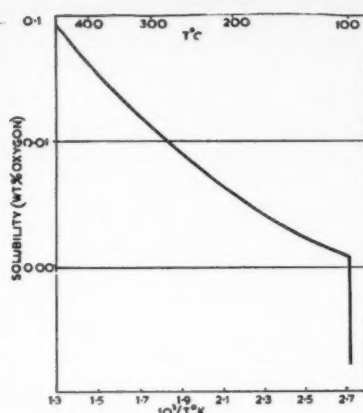


Fig. 2. Solubility of oxygen in liquid sodium.

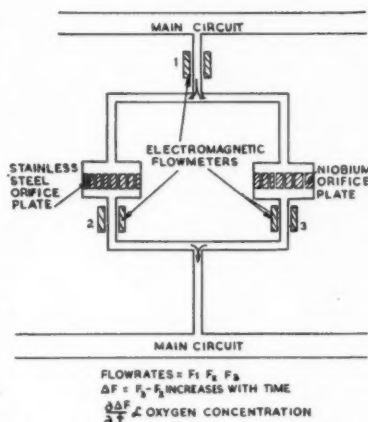


Fig. 3. Sodium corrosion meter.

cipitated oxide is left behind. This device, the cold trap, is packed with stainless-steel mesh or wool, presenting a large surface area to which the oxide will adhere. The oxygen content remaining depends on the trap temperature. Viscosity limits the lower temperature to about 150°C., equivalent to an oxygen content of 25 to 30 p.p.m.

It is often required to reduce the oxygen content further to prevent the corrosion of reactive circuit materials. The sodium is then passed through a hot trap containing zirconium or titanium heated to 600 to 650°C. The hot trap element in the form of a foil is oxidised, thus effectively removing oxygen from the liquid metal. It is theoretically possible to reduce the oxygen level to well below 1 p.p.m., although continuous in-leakage usually prevents this, but levels of 3 to 5 p.p.m. are readily attainable.

As an alternative to hot trapping, soluble getters may be used to remove oxygen from the circuit. Suitable

materials must be soluble in sodium, be preferentially oxidised and form insoluble oxides. Examples of practical importance are magnesium, barium and calcium. The oxides formed are filtered off in a by-pass circuit. Soluble getters are rather more efficient than hot traps, as they operate throughout the circuit, removing oxygen at points where it enters, but they have serious disadvantages. The additions, particularly calcium, increase the corrosive action of the coolant, while the suspended oxides are erosive.

Provision must be made for the measurement of oxygen contents to check the efficacy of the clean-up methods. The method used depends on the oxygen level to be measured. For high concentrations, i.e. greater than 20 to 30 p.p.m., the plugging meter is employed. A small by-pass flow is passed through an orifice or narrow section of pipe, the temperature of which is progressively reduced. The solubility of oxygen is reduced until blockage of the meter occurs. The oxygen concentration is the saturation level at the plugging temperature.

A corrosion meter (Fig. 3) is used for low oxygen levels. A by-pass flow is diverted through two orifice plates arranged in parallel. Flow meters measure the flow through each. When the meter is heated to 500 to 600°C., the niobium plate is corroded, enlarging the holes and allowing an increased flow to pass while the stainless-steel plate is unaffected. The rate of increase of flow through the niobium can be calibrated in terms of oxygen content.

Coolants are required for valves, pumps, motors and other mechanisms in the sodium circuit. Because of the risk of reaction, water cannot be used and gas cooling cannot usually be applied. These restrictions have led to the use of organic liquids such as *Tetralin* and toluene.

The good heat-transfer properties of sodium make it more than ever essential that pipework shall be lagged to minimise heat losses. Materials must be free from water, present either as moisture or in chemical combination. Suitable insulation may be obtained by using mineral-fibre felts, mineral-wool block or moulded glass-fibre block.

It is necessary to incorporate heating elements below the insulation, as the melting point of sodium, 97.8°C., is well above ambient. It is desirable to heat the main circuit to 150 to 200°C. before filling, thus providing a good margin against blockage in cold spots. External heating is only necessary during the commissioning period, as later fission-product decay in the



core and to a lesser extent  $\beta$ - $\gamma$  decay in the coolant maintains the sodium above its melting point.

### Material selection

Materials for use in a sodium circuit must: (a) withstand the corrosive attack of liquid sodium; (b) possess adequate mechanical and physical properties for the particular application; and (c) for parts within the core, have a low-neutron-capture cross-section.

Corrosion by liquid metals can proceed by one or more of five mechanisms: (1) solution of the solid in the liquid metal; (2) solid solution of the liquid metal in the solid; (3) intergranular penetration of the solid metal; (4) formation of intermetallic compounds; or (5) formation of chemical compounds with impurities dissolved in the liquid metal.

It is necessary to test potential circuit materials thoroughly to assess their behaviour in liquid sodium. Tests must evaluate the effects of temperature, flow rate and sodium purity over the ranges which will be found in the reactor. Typical conditions will include temperatures of 300 to 650°C., flows up to 30 ft./sec. and oxygen contents up to 30 p.p.m.

Three test methods are commonly used for the evaluation of materials for sodium service. The simplest is the autoclave test which, being static, is limited to providing preliminary data from sorting tests. The autoclaves are usually made from austenitic stainless steel, fitted with thermocouple pockets and provision for maintaining a near-static inert gas blanket over the sodium surface. A refined autoclave test has been devised in which a partly filled, non-isothermal vessel is oscillated, alternatively immersing and exposing the specimens.<sup>2</sup> Limited data on mass transfer and effects of oxygen content were obtained.

Simple dynamic experiments may be carried out in a thermal convection loop. A closed loop in the vertical plane has the opposite vertical sides heated and cooled, inducing a flow. Velocities of 5 to 10 ft./sec. are obtainable in this type of apparatus.

Refined experiments in which all the variables may be accurately controlled require the use of a pumped loop. The heated experimental section is followed by an economiser, beyond which a further cool experimental section may be installed. Hot and cold traps may be incorporated for purity control. Large pumped loops may be used for the calibration of instruments and component testing as well as for corrosion testing.

### Behaviour of structural materials

A great amount of data has been amassed on the behaviour of materials in sodium, but there is still some disagreement and fundamental mechanisms are far from completely understood. Two attack mechanisms of the five previously listed are significant when discussing materials for reactor construction. The dissolution of metals in liquid sodium is the basis for mass transfer attack. Material is taken into solution, carried in the liquid metal and precipitated in a different part of the circuit. Mass transfer occurs in both isothermal and non-isothermal environments, the former being a diffusion-controlled mechanism and the latter depending on the variation of solubility with temperature. In both cases, the oxygen content of the sodium is an important variable.

The second type of attack experienced in reactor systems is also strongly dependent on oxygen contamination. Some metals may be oxidised by sodium oxide, the reaction being very similar to that experienced in other oxygen-containing media. Where the oxide produced is non-protective, serious damage may occur on prolonged exposure.

### Mass transfer

Much work has been concentrated on the behaviour of ferrous materials because of their availability, low cost and well-known technology as materials of construction. Austenitic stainless steels have been used in all the reactor systems at present operating, the choice being strongly influenced by their established corrosion-resisting properties in other media.

It was quickly established that corrosion rates of these steels were so low as to cause no concern over the weakening of structural members and the extent of mass transfer would raise no problems of blockage in cool parts of the circuit.<sup>3</sup> Steel within the core becomes radioactive and mass transfer results in the transport of active species to all parts of the primary circuit. This mechanism represents a potential hazard to maintenance for, whereas the sodium activity is short-lived, some of the species from the steel have long half-lives. It was found that the deposited activity could not be cleaned out as it diffused into the pipework, sometimes to a depth of several thousandths of an inch.<sup>4</sup>

Mass-transfer experiments in a dynamic in-pile loop were made on the mass transfer from an 18/10/1 (type 347) steel.<sup>5</sup> The deposited

material contained manganese ( $Mn^{54}$ ), tantalum ( $Ta^{182}$ ), iron ( $Fe^{59}$ ), cobalt ( $Co^{60}$ ) and chromium ( $Cr^{51}$ ) in order of decreasing activities. The high manganese content results from a (*n, p*) reaction with  $Fe^{54}$ , not from manganese in the steel. It should be noted that the composition of the transferred material is quite different from that of the original material. The average transfer rate from this test, operated at 480°C., was only 1 mg./sq.dm.mo.

Numerous capsule tests have been carried out in support of the in-pile data to evaluate variables. The most striking results were obtained on the effect of oxygen in the sodium. An increase of oxygen content from 30 to 100 p.p.m. increased the transfer rates of iron by a factor 17 and of cobalt by 54.<sup>6</sup> Isothermal tests at various temperatures revealed an exponential increase in transfer rate with temperature, indicating a diffusion-controlled mechanism. No effects of temperature gradient or velocity have been observed, substantiating the diffusion theory.

The conclusion drawn, that austenitic stainless steels are satisfactory for service at temperatures up to 550°C. in sodium of low oxygen content, is now well substantiated by reactor operating experience. However, in sodium containing 0.5 wt.% oxygen, stainless steels are severely attacked at 700°C. Preferential dissolution of nickel occurs, leaving a porous ferritic structure.<sup>7</sup>

It is desirable in certain cases to replace stainless by carbon or low-alloy steels. Carbon steels suffer decarburisation and are subject to mass transfer at much greater rates than austenitic steels. Both problems can be reduced by the addition of chromium. The addition of 12% yields a steel which has comparable properties to an 18/8 tube, i.e. a transport rate of 1 to 2 mg./sq.dm.mo. at 500°C. A much lower chromium content is required to reduce decarburisation to a negligible extent. Metallographic studies indicate that 1 to 2% chromium is adequate for this purpose. The complete circuit must be considered with respect to decarburisation, as a large area of austenitic steel will act as a carbon sink, permitting the reaction to continue with deleterious effects to both materials.

Low-alloy steels are more sensitive to oxygen levels than are the austenitic types, particularly at levels about 100 p.p.m. Increases above this level produce pitting and intergranular attack.<sup>8</sup>

Mass transfer of iron or low-alloy

steels probably proceeds by the formation of a complex oxide  $\text{FeO}(\text{Na}_2\text{O})_2$  which is reduced to iron and  $\text{Na}_2\text{O}$  by sodium.<sup>9</sup> Direct formation of  $\text{FeO}$  is thermodynamically prohibited, but surface energies probably permit the complex oxide to form.

### Oxidation attack

It will be appreciated, from the stress placed on the role of oxygen in mass transfer, that there is no firm dividing line between it and oxidation attack, one accompanying the other in most cases. Arbitrarily, oxidation attack can be discussed with reference to the reactive metals, zirconium and niobium.

Comparison of the behaviour of these metals and steels must be influenced by their roles in the reactor. Steel structural components are massive compared with the corrosion rates to which they are subjected, but the transport of active material represents a circuit hazard. Niobium and zirconium are used in thin sections, so that material losses are significant but transferred activity is of a low order.

Zirconium is readily oxidised, but forms a protective film causing a parabolic decrease in reaction rate. Free energy data show that it will reduce  $\text{Na}_2\text{O}$  at all temperatures of interest. The dissociation pressure of  $\text{ZrO}_2$  in oxygen,  $10^{-30}$  atm. at  $550^\circ\text{C}$ ., is much lower than that of  $\text{Na}_2\text{O}$ ,  $10^{-20}$  atm.<sup>10</sup> It is, therefore, impossible for  $\text{Na}_2\text{O}$  to exist in equilibrium with zirconium.

Experiment has confirmed that zirconium is oxidised in oxygen-bearing sodium, the rate being unaffected by oxygen contents above 20 to 50 p.p.m.<sup>11</sup> Typical rates are 0.5 mg./sq.cm.mo. at  $500^\circ\text{C}$ . and 2 mg./sq.cm.mo. at  $600^\circ\text{C}$ . The exponential variation of rate with temperature and the independence of velocity infer that the reaction is controlled by the diffusion of oxygen ions through the oxide film, as would be expected from comparison with the behaviour in other oxidising media.

Niobium, which is the canning material used in the Dounreay fast reactor, is readily oxidised and so is expected to be influenced by the oxygen levels in sodium. The work of Davis and Draycott<sup>11</sup> shows the marked dependence of corrosion rate on the oxygen level. To reduce the corrosion rate to  $10^{-4}$  in. penetration/mo. at  $600^\circ\text{C}$ . the oxygen content must be kept below 5 p.p.m. Efficient hot trapping or gettering is required to achieve this standard.

Corrosion tests on niobium show a uniform rate of weight loss, indicat-

ing continuous removal of the oxidation product. The amount of the product adhering to the specimen is too small for accurate analysis, but a mixed oxide corresponding to the formula  $(\text{Na}_2\text{O})_4\text{Nb}_2\text{O}_5$  has been isolated from cold-trap residues. It is probable that this compound dissociates releasing  $\text{Na}_2\text{O}$  to continue the corrosion.<sup>11</sup>

### Circuit components

The peculiar properties of sodium demand a special approach to the design of pumps, valves, heat exchangers, etc.

Electromagnetic pumps are often used in preference to mechanical types, as they employ no moving parts. These are based on the motor principle, i.e. a conductor in a magnetic field experiences a force. Two main types are commonly used. The Faraday type may be operated on either a.c. or d.c. The coolant passes through a rectangular section pipe between the poles of an electromagnet. A transverse current is passed through the liquid metal stream.

Faraday pumps have the advantages of simplicity and high throughputs (500 gal./min.) but at low pressures. Pumping efficiencies are low.

Induction pumps of either helical or linear pattern are more complicated, but are more efficient than the Faraday. Polyphase-wound stators produce a travelling magnetic field which interacts against a current carried in the sodium. The helical type closely resembles an induction motor, the sodium being contained between the stator and a fixed rotor. Rotational motion in the liquid is translated into axial motion by a helix on the rotor. In the linear pattern the coolant passage is a narrow rectangle, the stators being perpendicular to the long sides. The liquid is carried by the travelling magnetic field.

Helical pumps develop high pressures at low flow rates, while linear induction pumps are capable of high flows ( $>1,000$  gal./min.) at moderate pressures (150 p.s.i.).

### Heat exchangers

The design of sodium-service heat exchangers is strongly influenced by the need for guaranteed integrity to prevent the leakage of active sodium in the primary exchanger and the reaction between sodium and water in the secondary exchanger. The former problem is the lesser of the two and a high-quality, all-welded tube and shell exchanger is often regarded as being satisfactory.

Three alternative designs for the secondary exchanger have higher in-

tegrity but at the expense of efficiency. The best of these is probably the conducting-bridge type. The liquids are contained in single tubes set in a block of high-conductivity material. Thermal contact is ensured by brazing the interfaces. This type of exchanger, although costly, is used in the Dounreay fast reactor.

The composite tube and shell exchanger uses concentric tubes, one heat-transfer medium being carried in the inner tube while the other is on the shell side. The tube interspace contains an intermediate fluid which is monitored for leaks from either system. The double tube and shell exchanger carries the two media in separate tubes, the shell containing an intermediate fluid to promote heat transfer. This is the least efficient of the types described.

### Conclusions

Sodium-cooled reactors can be designed and operated with confidence, although many fundamental problems are as yet unsolved. Research into the relative contribution of solution and diffusion in the mass transfer of steels, and the role of oxygen in all reactions, is continuing. Further study is required of methods of oxygen removal as the maintenance of sodium purity should enable operating temperature increases to be made.

Within the next few years operating experience will be available from very large sodium-cooled reactors, firmly establishing this type in the overall nuclear power generation programme.

### Acknowledgment

The author wishes to thank Sir Leonard Owen, until recently Managing Director (I.G.), and the Research Director, Dr. H. Kronberger, for permission to publish this article.

### REFERENCES

- <sup>1</sup>Metal Prog., 1957, **71** (3).
- <sup>2</sup>C. B. Jackson et al., 'Liquid Metals Handbook,' Na-NaK Supplement, 1955.
- <sup>3</sup>T. Trocki and D. B. Nelson, *Mech. Engg.*, 1953, **75** (6), 472.
- <sup>4</sup>E. G. Brush and R. F. Koenig, *Nuclear Metallurgy*, 1956, (2), 21-32.
- <sup>5</sup>F. G. Haag, *Chem. Eng. Prog.*, Symposium No. 2, 1957, **53**, 43-50.
- <sup>6</sup>J. W. Manstetter and S. J. Rodgers, *MASC-36* (1954).
- <sup>7</sup>E. G. Brush, *Corrosion*, 1955, **11** (7), 27-31.
- <sup>8</sup>E. G. Brush and R. F. Koenig, *KAPL-1103* (1954).
- <sup>9</sup>G. W. Horsley, *A.E.R.E. M/R* 1141 (1954).
- <sup>10</sup>F. E. Borman and D. D. Cubicciotti, *J. Amer. Inst. Chem. Engrs.*, 1956, **2** (2), 173-176.
- <sup>11</sup>M. Davis and A. Draycott, 2nd Geneva Conf., 1958, p. 25.

# ION EXCHANGE

## (Inorganic Technological Applications)

By **J. A. R. Genge, M.Sc., A.R.I.C.**  
(Battersea College of Technology)

SINCE the last review on ion exchange published in this journal,<sup>1</sup> many improvements to existing processes have been reported and some new applications and techniques have been described. It is, nevertheless, still true to say that the purification of water remains the largest single industrial application and, in this respect, the use of ion-exchange membranes is becoming more important. Metallurgical extraction processes are the next general type of application in order of importance and, in particular, the extraction of uranium. In fact, the uses associated in one way or another with atomic energy are becoming increasingly numerous and varied. In addition to these larger-scale uses, there are many smaller ones which have been suggested or to which improvements have been made, particularly in the ion-exchange treatment of waste liquors for the reclamation of some valuable material or in helping to solve effluent disposal problems.

This article, which has been restricted to inorganic technological applications, covers principally work reported over the last year but an attempt has been made to group the various applications into general techniques and to give some idea of the scope in each case.

### **Ion-exchange materials**

A large number of patents have been taken out and papers published describing new methods and improvements to old methods of making ion-exchange resins. A wide variety of organic polymers have been suggested, but, for most purposes, resins based on a polystyrene matrix still appear to be the most suitable with regard to insolubility, chemical inertness and general toughness. It has often been claimed, however, that almost any material, with appropriate treatment, can be converted to an ion exchanger and this may prove very attractive either economically or as a method of disposal of some unwanted by-product. Preparations have been described starting from a number of materials including casein and soya bean,<sup>2</sup>

cashew nut shell<sup>3</sup> and wood pulp.<sup>4</sup>

One of the main disadvantages of most ion-exchange resins, especially when used for metal extraction processes, is their lack of specificity and the preparation of a resin specific to one ion has always been an attractive proposition. Many attempts have been made in the past to prepare such a resin,<sup>5</sup> but the products have usually had the disadvantages associated with the early ion exchangers, namely low capacity, instability and limited conditions under which they could be used. More recent attempts at preparing a specific resin include the preparation of cation exchangers showing some selectivity for the uranyl ion. These are phosphorylated polymers obtained, for example, by polymerising triallyl phosphate.<sup>6, 7</sup> Another recent example is a process for the recovery of uranium from copper-bearing solu-

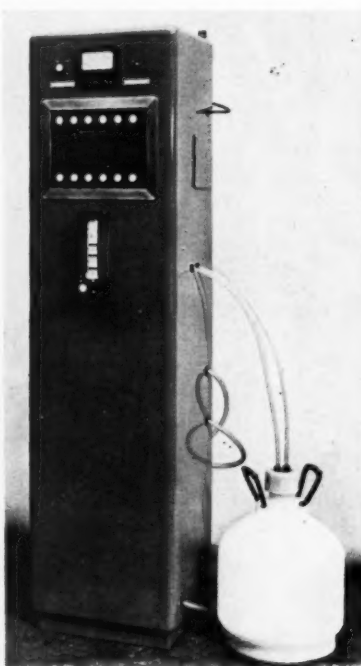
tions.<sup>8</sup> A solution containing iron, aluminium, copper and uranium as nitrates is passed over a resin having functional enolisable 1:3 diketo groups. Copper and uranium only are adsorbed and these can be removed individually, uranium with a carbonate solution and copper with an alkali cyanide solution.

Synthetic ion exchangers, based on an organic polymer matrix, although very stable and suitable under most working conditions, cannot be used at very high temperatures. Also, if exposed to very strong ionising radiation, most resins tend to suffer a drop in exchange capacity. Both these factors are important when the resins are used in some atomic energy installations and attempts have been made to find an exchanger which is able to stand up to these conditions. It has been found that certain inorganic materials such as the oxides, phosphates, arsenates, tungstates and molybdates of some transition metals, notably zirconium and titanium but also of thorium and tin,<sup>9, 10, 11</sup> have ion-exchange properties and are more resistant to high temperatures and radiation. It has also been noted<sup>12</sup> that zirconium oxide or phosphate precipitated from citrate solutions have some special exchange properties associated with the presence of citrate in the material.

An interesting material described very recently<sup>13</sup> is an ion-exchange resin based on a semi-conducting matrix formed by polymerising xanthine dye type molecules. Such an exchanger would have the advantage that it could be regenerated electrically.

### **Liquid ion exchangers**

A different class of material which has been developed is the liquid ion exchanger. The ordinary solid resinous exchanger consists of active groups attached to an insoluble polymer network. Liquid exchangers are similar but, in this case, the active groups are attached to quite small organic molecules containing 8 to 12 carbon atoms. The whole molecule is then liquid at normal temperatures. Cation exchangers of this type which have been



[Photos Courtesy: Permutit Co. Ltd.]

**A 6-in. mixed-bed panel-type 'Deminrolit' unit with aspirators.**



described are alkyl phosphoric acids and other organo-phosphorus compounds,<sup>14</sup> while anion exchangers consist of long-chain amines.<sup>15, 16</sup>

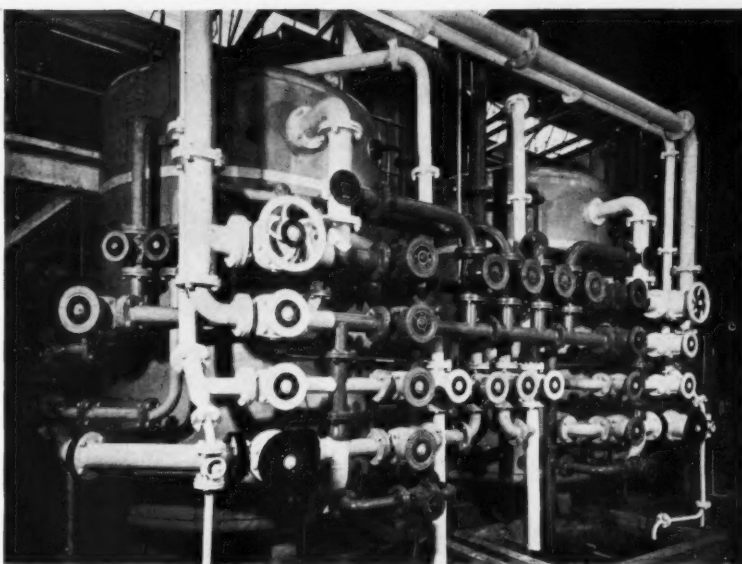
The equipment and techniques used with these materials are very similar to those used for solvent extraction procedures and the use of liquid ion exchangers has been suggested for the extraction of uranium and other metals.<sup>9</sup> Some of the proposed uses appear to have considerable advantages over the corresponding methods using solid ion exchangers. For example, the direct leaching of uranium ores with liquid exchangers would appear to be comparable with the resin-in-pulp procedure using normal resins.

### **Metallurgical processes**

The principal application of ion exchange in this field remains its use in the extraction of uranium from its ores, many of which are very low grade. As described in the previous article,<sup>1</sup> this type of extraction is based upon the existence of a complex anion which is specific for the metal in question. Thus uranium is converted to the anion  $UO_2(SO_4)_3^{4-}$  and the metal is extracted by sorption on to an anion exchanger and, since this complex sulphate anion is formed only by uranium under these conditions, the metal can be extracted efficiently from a very low-grade material such as the South African gold-bearing ores after extraction of the gold. The process can be improved further by using a resin-in-pulp procedure involving direct contact between the resin and the sulphuric-acid-treated pulp, thus avoiding an expensive filtration stage and permitting the whole process to be made continuous.

A similar process, also described fully in the last article, is the recovery of gold and some other metals from cyanide solutions. In this process again, the gold is present as an anionic aurocyanide complex which can be sorbed on to an anion-exchange resin.

An alternative procedure which can be employed for the separation of metals from each other is that of complexing elution. Briefly, the mixture of cations is sorbed on to a column of cation exchanger and then removed individually or in groups by elution with one or more suitable complexing agents. It is, of course, necessary that the complexes formed with the eluant are either specific for one metal or, if formed with all the metals, have differing stabilities. Classical examples of the use of this technique are the separation of the rare earth metals and of the transuranium elements with



Mixed-bed units at the Permutit chromate swill treatment plant at Morris Motors.

complexing agents such as citric, tartaric and ethylenediaminetetra-acetic acids. This application to the rare earth elements is rather unique. The affinity of the resin for an ion will depend upon the size of the hydrated ion and the least firmly held will be the one with the smallest non-hydrated or largest hydrated radius. Thus, with the rare earth metals, as a result of the 'lanthanide contraction,' the order of affinities rises from lutecium to lanthanum. The reverse tends to be true for the stabilities of the complexes formed with the eluant and, as a result of the combination of these two effects, it is possible to achieve separations of these very similar elements.

There have been some developments in this type of process and a method has been proposed for the rapid ion-exchange separation of large quantities of the rare earth metals using ammonium nitrilo-triacetate as the eluting agent.<sup>17</sup> Another process has been described for the separation of the platinum metals using an elution technique.<sup>18</sup> This process is interesting, as it depends upon the formation of specific ions, namely chloro and perchloro complexes. Rhodium, ruthenium and iridium are eluted with 2M hydrochloric acid, palladium with 9M hydrochloric acid and platinum with 2.4M perchloric acid. The rhodium and iridium can be separated from each other by a second similar process. A method has also been proposed for the removal of ruthenium from uranyl nitrate solutions by sorption on to a cation exchanger.

In addition to the above, there have been a large variety of separations suggested on an analytical scale and a number of these would probably be quite suitable for expansion to a larger-scale process if the need arose. An example of this is the separation of rhodium and iridium from large quantities of iron, nickel and copper<sup>20</sup> and another example is the separation of niobium and zirconium by elution from a cation exchanger with hydrochloric acid containing oxalic acid and hydrogen peroxide.<sup>21</sup>

### **Waste and effluent treatment**

The new development in this field is the application of ion exchange to the treatment of radioactive wastes and there have been several references to this recently.<sup>22, 23, 24</sup> Another application is in the treatment of plating wastes.<sup>25</sup> Ion-exchange methods have been used for the recovery of copper, nickel and chromium from waste plating solutions. They are also being used increasingly in the analysis of this type of solution which, containing as it does, not only several metals, but also complexing anions, is not easily analysed without some preliminary separations. Waste cyanide solutions are being treated for reclamation of the cyanide by ion-exchange methods, a process not only useful for saving the cyanide but also providing a method for treating this type of effluent.

In addition to these uses, there have been many others developed, such as the recovery of copper from cuprammonium rayon plant wastes, the treat-

ment of coke-oven wastes, the recovery of ammonia from various ammoniacal liquors and the treatment of waste sulphite liquors from the paper pulp industry. Ion exchange is, in many ways, ideally suited to waste and effluent treatment as it represents a simple method, not only of de-ionising these solutions, but also of concentrating the ions so collected.

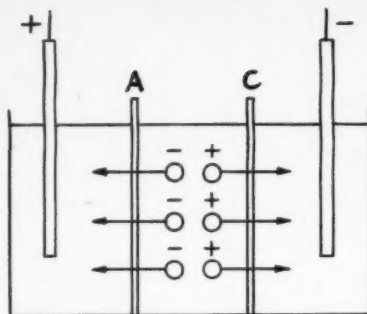
### Water treatment

It has already been stated that water treatment of one type or another remains the largest single use of ion exchange. The general principles of water softening in this way are now well established and most of the references which have appeared in the literature recently are concerned either with development of plant and improvement in design or with very specialised applications.

In the atomic energy field, heavy water can be both purified from ordinary water and deionised by passage through a mixed bed with the resins in the deuterium form.<sup>27</sup> Ion exchange has also been used for deionisation of the cooling water for atomic energy plants and, where necessary, for the removal of activity.<sup>28</sup> The various applications of ion exchange to both industrial and municipal water supplies has been reviewed elsewhere<sup>29</sup> and it is worth noting that these methods are becoming increasingly popular for treatment of water to be used in highly critical systems such as high-pressure boilers and equipment for this purpose has been developed using both natural zeolites and synthetic resins.<sup>30</sup>

### Ion exchange membranes

One of the biggest disadvantages of most ion-exchange processes is that they cannot be made continuous as there has to be a regeneration stage with the resin out of the system. It is true that this disadvantage has, to some extent, been overcome by using a three-column process or a resin-in-pulp method, but the most attractive and elegant process which avoids the difficulty altogether is electrodialysis using selective ion-exchange membranes. These membranes will permit passage of one type of ion only and a simple three-compartment cell using one anionic and one cationic membrane is shown in the accompanying diagram. When a potential is applied to such a cell, a current flows with anions from the centre compartment passing through the anion-exchange membrane A into the anode compartment and cations from the



Three-compartment cell (see text).

centre compartment passing through the cation-exchange membrane C into the cathode compartment. The solution in the centre compartment is thus deionised although, as would be expected, the efficacy of the cell drops when this ionic strength becomes very low.

For large-scale applications many of these cells can be ganged together. One disadvantage has been that the membranes were brittle and apt to crack and many patents have been taken out giving methods of preparing tougher membranes. There are two types: homogeneous, where the whole membrane is an ion exchanger; and heterogeneous, where the membrane is some tough, porous material such as Fibreglass with an ion exchanger dispersed through it. The latter type is usually the stronger.

Some large-scale plants employing electrodialysis have been constructed. For example, in South Africa and in Holland there are large water-treatment plants and in Tobruk a plant supplying 88,000 gal./day of water, the salinity having been reduced from 5,000 to 500 p.p.m.<sup>31</sup> The entire water supply for Coalinga, California, is supplied from an electrodialysis plant. The method is also used for deionising boiler feedwater<sup>32</sup> and coolant for atomic energy equipment.<sup>33</sup> Applications to the treatment of spent pickle liquor have been described,<sup>34, 35, 36</sup> and metallic iron and sulphuric acid of usable strength can be reclaimed. Membranes can also be used for the separation of metals, for example rare earth, and rare earth and thorium mixtures.<sup>37</sup> Other applications include the use of electrodialysis cells to purify the oxides of germanium, zinc, aluminium, tungsten and silicon for semi-conductor work.<sup>38</sup>

It will be apparent that the use of ion-exchange resins for many purposes is now well established and that an increasing number of smaller uses are

being proposed. Refinements to plant design are constantly being suggested and the newer developments like liquid ion exchangers and large-scale electrodialysis make a wider range of uses possible.

The author wishes to thank the Permutit Co. Ltd. for their kind assistance in supplying the photographs included in this article.

### REFERENCES

- <sup>1</sup>D. A. Everest, *CHEMICAL & PROCESS ENGINEERING*, 1958, **39**, 347.
- <sup>2</sup>M. Mendelsohn, U.S. Pat. 2,838,482.
- <sup>3</sup>K. P. Govindan and N. Krishnaswamy, *J. Sci. Ind. Res. (India)*, 1958, **17**, 416.
- <sup>4</sup>M. A. Millett, J. S. Schultz and J. F. Saeman, *Tappi*, 1958, **41**, 560.
- <sup>5</sup>D. K. Hale, *Research*, 1956, **9**, 104.
- <sup>6</sup>J. Kennedy, R. V. Davies, H. Small and B. K. Robinson, *J. Appl. Chem.*, 1959, **9**, 32.
- <sup>7</sup>U.K.A.E.A. (J. Kennedy), *Brit. Pat.* 777,248.
- <sup>8</sup>R. Kunin, U.S. Pat. 2,863,717.
- <sup>9</sup>C. B. Amphlett, L. A. McDonald and M. J. Redman, *J. Inorg. Nucl. Chem.*, 1958, **6**, 220.
- <sup>10</sup>'Peaceful Uses of Atomic Energy,' *Proc. 2nd Int. Conf. Geneva*, 1958, **28**.
- <sup>11</sup>E. Merz, *Z. Elektrochem.*, 1959, **63**, 288.
- <sup>12</sup>C. B. Amphlett, G. H. Nancollas and T. Williams, *Chem. & Ind.*, 1959, 292.
- <sup>13</sup>*Chem. & Engg. News*, 1959, **37** (26), 30.
- <sup>14</sup>T. H. Siddall, *Ind. Eng. Chem.*, 1959, **51**, 41.
- <sup>15</sup>U. Schindewolf, *Z. Elektrochem.*, 1958, **62**, 335.
- <sup>16</sup>T. Bizot and B. Tremillon, *Bull. Soc. Chim. France*, 1959, 122.
- <sup>17</sup>L. Wolf and J. Massonne, *Chem. Tech. Berlin*, 1958, **10**, 290.
- <sup>18</sup>S. S. Berman and W. A. E. McBryde, *Canad. J. Chem.*, 1958, **36**, 835.
- <sup>19</sup>C. A. Prohaska, R. J. Dietz and H. E. Henry, U.S. Atomic Energy Comm., 1958, DP-291.
- <sup>20</sup>A. E. Marks and F. E. Beamish, *Analyt. Chem.*, 1958, **30**, 1464.
- <sup>21</sup>H. Sano and R. Shioni, *J. Inorg. Nucl. Chem.*, 1958, **5**, 251.
- <sup>22</sup>A. L. Medin, *Ind. Eng. Chem.*, 1958, **50**, 989.
- <sup>23</sup>R. Saddington, *Trans. Inst. Chem. Eng.*, 1958, **36**, 350.
- <sup>24</sup>D. H. Logsdail, *Ind. Chem.*, 1959, **35**, 213.
- <sup>25</sup>*Electroplating & Metal Finishing*, 1957, **10**, 116.
- <sup>26</sup>E. Goldblatt, *Ind. Eng. Chem.*, 1959, **51**, 241.
- <sup>27</sup>G. M. Allison, *Canad. J. Chem. Eng.*, 1958, **36**, 217.
- <sup>28</sup>F. C. Haas, U.S. Atomic Energy Comm., IDO 16463, 1958.
- <sup>29</sup>R. G. Tredgett, *Munic. Util.*, 1958, **96** (7), 56.
- <sup>30</sup>J. Arthurs, J. A. Robins and T. B. Whitefoot, *Chem. Age*, 1959, **81**, 179.
- <sup>31</sup>W. Boby, *Ibid.*, 501.
- <sup>32</sup>R. E. Briggs, U.S. Pat. 2,838,449.
- <sup>33</sup>P. Cohen, *Ind. Eng. Chem.*, 1959, **51**, 66.
- <sup>34</sup>A. W. Harris and C. D. Strickler, U.S. Pat. 2,865,823.
- <sup>35</sup>D. J. Lewis and F. L. Tye, *J. Appl. Chem.*, 1959, **9**, 279.
- <sup>36</sup>G. W. Bodamer and C. Horner, U.S. Pat. 2,810,686.
- <sup>37</sup>K. Bril, S. Bril and P. Krunholz, *J. Phys. Chem.*, 1959, **63**, 256.
- <sup>38</sup>G. H. Morrison and R. L. Rupp, U.S. Pat. 2,814,592.

## Project Engineering

By W. V. M. Kelly

(P. G. Engineering Ltd., Power-Gas Group)

*This article discusses the responsibilities of the project engineer and his role in co-ordinating the efforts of the various service departments of a contracting firm, as well as in ensuring harmonious relations with the client and the smooth and economical progress of design and construction.*

TO define the functions and responsibilities of a project engineer\* is difficult for they vary considerably from country to country, between the purchasing and operating companies and the plant suppliers and even within these companies, depending on the type of project being handled. They may range from the investigation of preliminary schemes to determine approximate costs of the plant, utilities and products and the general feasibility of the scheme to, for an authorised project, the full responsibility for plant specifications and design, purchasing, progressing, inspection, construction and commissioning, and including financial control and analysis of final costs to provide data for future use.

In the United Kingdom it is usual on an authorised project for the functions to be generally as defined in the latter case. The degree to which the contractor's project engineer is responsible for technical specifications, as opposed to their assembly and distribution, will be determined by the individual's knowledge of the processes involved and the extent to which the contractor is responsible for basic design.

The project engineer's job begins when the project has been sanctioned and he has to arrange for the project to become a practical entity by seeing that the various services and facilities of his company play their appropriate part.

### Co-ordination of effort

The provision of process plant involving design, engineering, procure-

\* Chemical and petroleum industries are often influenced by American terminology which attributes to the project engineer the responsibility for technical design. Some U.K. firms avoid this inference by the use of other expressions such as 'contract engineer,' whose responsibilities are as outlined earlier, or 'project manager,' with similar functions but usually on larger projects which are handled by a more or less self-contained unit working under his direct control as opposed to the use of separate functional departments.

ment of equipment, site works and commissioning calls for a closely co-ordinated effort of almost every department within the contracting company and, although the functional organisation and systems may vary considerably between companies, depending upon the nature of their work and the contractual arrangements, it is more and more accepted that shorter programmes and higher efficiency are achieved by appointing one person to be responsible for every sizeable project.

The many service departments of the company will each provide the requisite technical skills and ability and handle their work efficiently provided they know what they are to do, when and how it is to be done, and the limitations of cost. Thus a main function of the project engineer is to ensure that every department receives full instructions and to check that they are meeting the contractual requirements. In this way he is the main contact with the clients to ascertain their requirements in terms of extent of work, programme and cost; he is the person to distribute this information within his own company and develop it, or arrange it, in suitable form so that departments can do their work in the sequences and ways appropriate to the requirements of others. His is the central position through which all information and requests are channelled and he directs in general terms the activities of all phases and types of work, leaving the heads of departments to provide the effort required of them in their particular and specialised fields. He is not in charge of the heads of departments, nor does he provide the technical direction. He is the co-ordinator combining the function of management with that of an engineer, and therefore his engineering training must be adequate and sufficiently broad to enable him to appreciate technical

problems and gauge how they affect specification requirements, programmes and prices. Similarly, he must be knowledgeable in many other fields such as purchasing, shipping, site works, costing and accounting. He must also have a personality enabling him to lead or drive others while maintaining their co-operation, for tighter programmes can only be achieved by drive from a leader who can depend upon the full co-operation of all contributors and sometimes on the acceptance of calculated risks.

### The project engineer's team

It is common for projects in the chemical and petroleum industries to be running at a rate of expenditure equivalent to £2 million p.a., yet the project engineer is responsible for work of this magnitude without having direct-line authority over the many officials and departments doing the work on his and other projects concurrently. For these reasons it is sometimes found advantageous on very large projects to provide the project engineer with an almost completely self-contained team to concentrate solely on the work of his project under his direct administration. But, since even then the team cannot be expert in all the technical matters, the project engineer must be able to draw upon the assistance of the company's more senior specialist personnel.

### Organisation of the programme

Regardless of the company's organisation it is essential that when a person is charged with the execution of a project he shall be quite clear to whom he is responsible. Also he must be assured that all the necessary facilities and services are available, and able to perform the functions required of them in accordance with the project plans. He, in turn, must ensure that they receive all necessary data by the appropriate times. Consequently, one





[illegible]

**Fig. 2. Method of forecasting ultimate cost of a project.**

plant should be permitted. Changes designed to provide small improvements in layout or operation may be left until after commissioning. It must be appreciated that all delays can be evaluated in monetary terms; to the contractor it is costly to have men and tackle standing idle—it can be bad for

morale to the point where output deteriorates and conditions become conducive to labour problems; to the purchaser the loss in interest on tied-up capital, the loss of profit on product sales and the cost of additional staff time are equivalent to additional daily expenditure of some significance.

### Liaison between purchaser and supplier

Project engineers as liaison officials between purchaser and supplier should seek to promote the closest relations between all other members of their companies and to establish a goodwill based on mutual respect so that each can fully understand the problem of the other and each will know that on completion of the project the contracting parties will be fully satisfied. To these ends it is desirable for designers to be free in their exchange of data and views, for the purchaser to know, as far as contract conditions allow, the financial status of the project, for construction teams to operate together and for the project engineers to be open and frank with each other in all matters relating to progress. Quite often purchasers are able and indeed willing and anxious to give useful assistance in retrieving positions causing concern for progress. Often they fully understand that additional expenditure to relieve a difficult position will be to their ultimate advantage.

### Cost control

A further important function of the project engineer is to ensure the financial success of the contract by controlling expenditure. For this purpose it is necessary to have at the outset of the project an estimate of total cost built up in such a way as to show the amounts of money available for various staff services, large items of equipment or categories of smaller equipment, site works and contingencies, etc.; soon after work has been started this estimate should be extended in the greatest possible detail and made available to all departments whose work can have a direct effect upon expenditure and to those concerned with financial budgeting. The accuracy with which costs can be controlled is a function of the degree to which the cost-control estimate is detailed, as is the freedom with which departments can make commitments without reference back to the project engineer. Although he will be advised of expenditure and commitments by the normal costing systems it is necessary to make periodic reviews of the anticipated financial outcome of the project having particular regard to possible variations in known commitments, unexpected expenditures and commitments still to be made. This function is generally best done by the project engineer's team as they are able to seek information from various sources and are in a position to appreciate the amount of work done and assess the value of

any changes which can cause differences in expenditure. They as a central body must also allocate the contingency allowances according to the merits of the claims made thereon.

Fig. 2 shows a simple system by which the ultimate cost situation can be forecast, provided expected commit-

ments are entered with a reasonably accurate knowledge of details of the job and assuming a fair balance between optimism and pessimism when assessing unknown values.

When the conditions of contract are such that the purchaser is charged with the actual costs of the project it

is essential that he should co-operate in the compilation of the cost-controlling documents, be aware of and approve expenditures and commitments, know the reasons for deviations from the estimates, and take part in the periodic assessments or forecasts of the ultimate financial position.

## Organisation of Chemical Plant Projects

By F. Roberts, B.Sc., F.R.I.C., A.M.I.Chem.E.

*This article discusses project organisation more from the point of view of those who have to operate the plant, although an attempt has been made to look at the subject impartially.*

A NEW chemical plant project has to be carefully planned from start to finish. The time scale has to be accurately foreseen and firmly controlled throughout the project. Financial expenditure at all stages must be known in advance, as accurately as possible, so that the necessary authorisations can be obtained. In short, the aim must be to enable all new process plant to be constructed and put into commission as quickly as possible and at the minimum cost.

In deciding upon methods of project organisation, the approach may differ, depending upon whether one is concerned with the project from the client's or the contractor's standpoint. In a recent symposium on the organisation of chemical engineering projects,<sup>1</sup> both 'sides' read papers on this subject; different points of view were advanced, some of which could not be reconciled. Again, the scale of new chemical projects varies enormously, and one would not decide to plan an extension (or addition) to an existing works plant in precisely the same manner as one would tackle a completely new works on a fresh site. Finally, if the process is well established, it may call for a rather different project organisation from the one which would be adopted for a novel process being commissioned for the first time.

No universal system can be laid down; different authorities have been successful to a greater or lesser degree with their own particular methods. The purpose of this article is merely to make some general points concerning the planning and organisation needed at various stages of a

fairly large chemical project, and to emphasise those requirements which are considered to be a necessary part of any system or organisation.

### Staffing the project

The first and most important requirement is a project leader. Fig. 1 shows how the various departments working on the project can be integrated through the project leader. Since many stages of the work overlap, it is desirable to have the same individual filling this important post throughout the whole project.

The foregoing may sound an ideal plan, but in practice it is often difficult to find the right sort of person for leader. A professional chemical engineer would seem at first sight to be an ideal choice, but there are at the present time very few really able men available with a wide enough experience of the various aspects of project engineering. In consequence, a mechanical engineer frequently occupies the position of project leader. However, if the family tree shown in Fig. 1 is strictly adhered to, it is difficult to see how the average mechanical engineer can be expected to cope with the chemical engineering aspects of the project. In practice, 'project leader' often means 'project engineer,' the latter having no jurisdiction over 'process engineering' and commissioning. In this case, the co-ordination of the whole project depends largely upon the successful working of a committee, or working party, which is chaired by a member of the board or other senior executive of the company.

One solution to the problem might

be the training up of a cadre of professional project leaders, starting from the time at which a man obtains his degree or other professional qualification.

A useful discussion on various alternative systems of project staffing was given by K. M. Curwen.<sup>1</sup>

### Phases of the project

Four clearly defined stages can be discerned:

- (1) *Appraisal:*
  - (a) Feasibility study.
  - (b) Development programme.
  - (c) Chemical flowsheet and cost estimate.
- (2) *Engineering of the project:*
  - (a) Plant flow diagram.
  - (b) Detailed design and drawing of plant items.
- (3) *Construction.*
- (4) *Commissioning.*

Although these stages may overlap to some extent, it will be useful to comment on each phase in turn before discussing the planning of the project as a whole.

The chemical engineer is responsible at the very outset for determining the technical and economic feasibility of the proposed project. If the decision is made to go ahead, a development programme may have to be mounted. This may involve compatibility and corrosion tests on alternative materials of construction, or the determination of essential scale-up information. The chemical engineer will have to ensure that the required data can be obtained within the time available. But the target for the end of the appraisal stage is the establishment of a final chemical flowsheet, giving the quan-



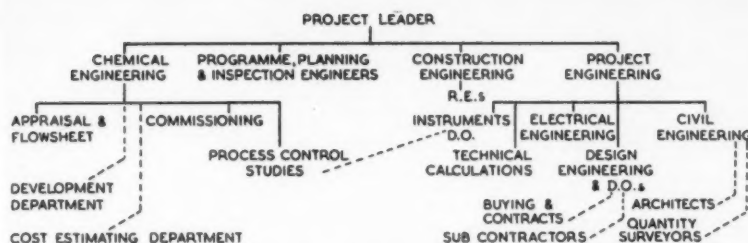


Fig. 1. Departmental organisation of staff engaged on a large new chemical plant project. Broken lines indicate responsibility for liaison with offices outside the project. Note: The need for special teams seconded to the project engineer depends on the size, novelty and complexity of the process.

ties of materials, the flow rates, and the mass and energy balances for every stage of the new process. A more detailed capital cost and operating cost can then be worked out in conjunction with the cost estimating department. However, the engineering of the project will normally have begun in earnest by now, and the process engineers will play a subsidiary role until the testing and commissioning of the plant has begun.

If an outside contractor is being employed, he will almost certainly be responsible for the engineering of the project, if in fact he has not been brought in at an earlier stage. The first task will be the preparation of the plant flow diagram, based on the chemical flowsheet. The flow diagram should show the number and sizes of all process vessels, and the methods of transferring materials between them. It will also indicate how the process is to be controlled and will include the requirements for steam, electricity, cooling water and any other necessary services.

The project engineer will be in direct charge of day-to-day work by this stage and, together with his design engineers and draughtsmen, will proceed to detail engineering design of the individual plant components. Detailed drawings of the latter will be prepared, and further drawings showing their position and housing will also be required.

A wide variety of specialist advice must be constantly drawn upon. Safety experts and operation staff will be consulted by the project engineering team. Also the original research and development team may be required to provide some last-minute information on any stage of the process which might have been 'thrown back' to them. Finally, the more difficult and specialised calculations must be passed to the technical section. (A chemical engineer attached to the project engineer can often conveniently look after the technical work going on

'extra murally' to the design office.)

The detailed specifications must be fed into the contracts branch, and it will be important to give priority to those items which are likely to be on long delivery. This is where foresight on the part of the project engineer may save a good deal of time.

A discussion of the construction stage falls outside the scope of this article. Two resident site officers, one a civil and the other a mechanical/electrical engineer, will normally be required. They will keep in close touch with the project leader, the latter being responsible for seeing that all vessels and other materials arrive on site according to schedule.

When commissioning commences, a chemical engineer with special plant experience should direct operations. This officer's responsibilities have been discussed at some length in an earlier article by the present author.<sup>2</sup>

### Programming and progressing

On a very large project the project leader should have a planning engineer working at his headquarters to assist in organising and planning the job as a whole. Programming means estimating the amount of work to be done in each phase and then establishing the terminal date for each operation so that they can then be arranged in an integrated sequence. A master plan is prepared initially, and then separate detailed ones are prepared for each aspect of the project. One of the first objectives of programming is the pinpointing of those features which set a lower limit to the period required for the complete carrying out of the project. Effort can then be focused on these key items. For example, it may be that a certain pressure vessel is required to be fabricated from some new material. Questions of design and material supply, the development of new welding techniques, the training of welders, or even the investigation of insurance matters may all contribute towards a long delay; but, when the

job is broken down, one individual item may stand out as being the main holdup. It is the responsibility of the planning office to find this out and then to progress the item periodically to see that the timetable, when fixed, is being adhered to.

Progressing requires a periodic comparison of the original programme with achievement, and this applies through all stages of the project. It is not sufficient to wait until a delivery date is reached, but the *percentage* completion must be ascertained and quoted to the project leader at frequent intervals of time. This may be conveniently carried out monthly by putting in broken lines under each of the continuous lines in the bar chart to represent actual progress to date.

The meeting of completion dates depends ultimately upon the authority, drive and acumen of the project leader himself. He must see that his planning office is efficiently run, so that he has all the facts on the project available at any given time, and he can then take any special action he thinks necessary from time to time. It may be that he should himself take early steps for seeing that a contract is placed for opening up and developing a new site. Or again, by studying other projects within the particular branch of the industry it may be possible to obtain the continuity of employment of teams of men with particular skills. All projects should maintain graphs showing the total build-up of financial expenditure (or committed expenditure) and also employed manpower. Such information may be invaluable where chemical firms have several new projects under way, or following each other in succession.

### In conclusion

It will always be found valuable to maintain adequate and careful records at all stages of the project. Such records should be carefully preserved, as they are often useful years later when memories are dim—sometimes as a record of why certain things were done in a certain way, sometimes as an aid in making modifications—and they do provide a means for the handing on of experience. It is a pity that more firms do not describe their project experiences openly, although the symposium referred to above was a step in the right direction.

### REFERENCES

- <sup>1</sup>17th Meeting of the European Federation of Chemical Engineering, Olympia, London, June 1958.
- <sup>2</sup>F. Roberts, *CHEMICAL & PROCESS ENGINEERING*, 1956, **37** (6), 192.

# Co-ordination of Effort in Planning and Erection

By W. Fletcher

(Constructors John Brown Ltd.)

*This article presents a further approach to planning and erection problems and outlines the various activities of the specialist departments which make up the design and construction team.*

**T**HE problem facing anyone who has decided to build a chemical plant may be stated as that of getting designs, materials, plant and men to the job site and of building to a properly phased programme.

The planning of such an operation is usually broken down into stages of design, procurement and erection, and as time is costly these are not consecutive but are phased concurrently as far as is practicable. The alternative to such concurrent phasing is a programme period which no longer interests progressive companies whose investments during construction may carry interest at several hundred pounds a day.

## Design

It is assumed that the economic studies have been completed and the site chosen, and that the capacities of the plant and its ancillaries are known. The design team will now be able to start work on the project and such a team will include specialist engineers responsible for the following branches:

Chemical and process engineering	
Mechanical	33
Civil	33
Electrical	33
Instrument	33

Their activities are co-ordinated by a project engineer who acts also as liaison with the client and other outside agencies.

The work commences with the preparation of a process flowsheet on which is shown process equipment, main flows and compositions, pressures and temperatures. The process flowsheet is the basis of all further work and must be agreed between contractor and client and 'frozen' at the earliest moment as subsequent changes, however attractive, can have serious effects on design cost and programme timing.

The next stage will be the preparation of an engineering flowsheet and the writing of specifications for process equipment such as vessels, fractionators, heat exchangers, pumps and

storage tanks which will be numbered and entered on an equipment schedule according to class.

In a well-planned programme equipment specifications will be issued first for those items of longest delivery so that orders may be planned to secure workshop capacity and the earliest delivery.

The engineering flowsheet or line diagram will show, in addition to equipment, all pipes and valves with sizes and references indicating materials of construction and insulation. From this flowsheet a valve schedule and a piping schedule can be prepared.

The engineering flowsheet will serve as a basic drawing to which the instrument engineer can add his control instruments and from which he can thus prepare a schedule of instruments and purchase requisitions.

A layout can now be agreed for the plant and the civil engineer may commence work on the design of earthworks, piling, roads, services and buildings. Although the civil engineer must wait on others for dimensions

and loadings of equipment before he can design foundations, his drawings are the first to be required on site. The civil engineer in a contracting organisation overcomes this difficulty by an intelligent anticipation of requirements based on past experience and discussion with his colleagues and will have notional studies available at a surprisingly early stage.

The mechanical section will meanwhile be proceeding with piping plans and elevations and/or a model of the plant. The use of models is a growing practice with great advantages both in giving clarity as a three-dimensional presentation and in replacing drawings with savings in time and money.

The electrical engineer starts late in the design programme and produces, firstly, local wiring for power and lighting in the plant areas based on the layout and models and, secondly, specified equipment and design installation for general power supply throughout the factory including transformer stations and high- and low-voltage switchgear.

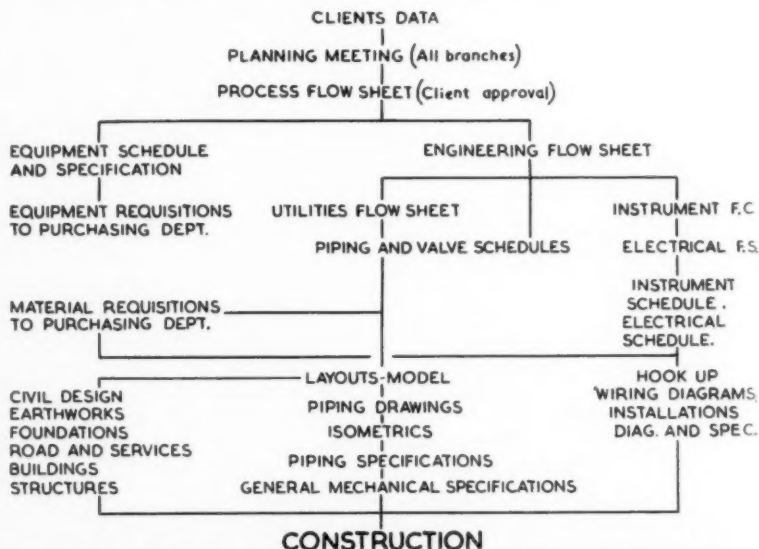


Fig. 1. Stages in design of a project, in chronological order.

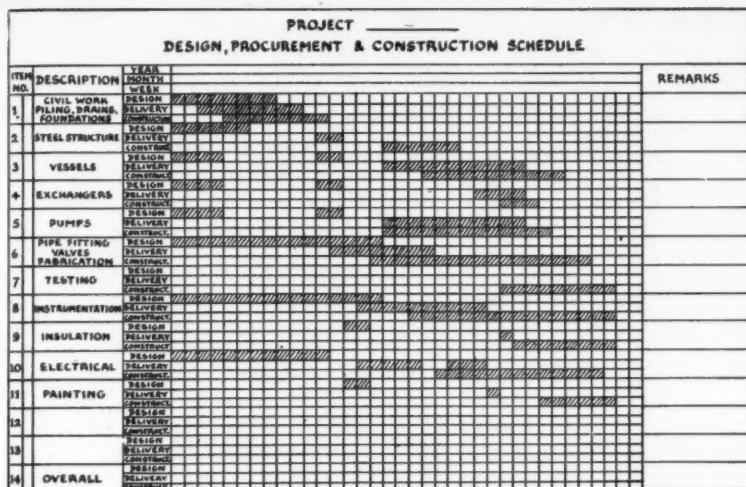


Fig. 2. Typical bar chart for timing design, delivery and construction.

The completion of the design programme will overrun the commencement of site work in a tightly phased project and the maintenance of a steady supply of drawings to site is a matter demanding constant attention.

The chronological development of design may be illustrated as in Fig. 1.

### Procurement

As shown above, the project requirements for equipment and material are presented to the buyer in the form of a requisition, together with a specification which may include a sketch showing approximate dimensions and connections. Specification sheets illustrated by Rose and Barrow<sup>1</sup> and by Curwen<sup>2</sup> are typical of those in general use by construction firms and fabricators. Their object is to ensure that quotations received are comparable by stating materials of construction, design codes, dimensions and connections required.

The buying department will have built up a record of performance of suppliers in respect of price, quality, and keeping of delivery promises. Experience can be quoted of failures to meet deliveries and claims for 'extras' in price which show that a few fabricators do not realise that immediate post-war conditions no longer apply.

Choice of supplier is usually made on the basis of price, delivery and reputation as shown in a quotation summary. It is considered that such choice should be agreed between buyer and engineer, but with the final word on technical grounds remaining with the engineers. A good buyer's knowledge of the market is an invaluable asset, and as about 60% of total job value may be in materials, the buyer's contribution to the financial success of a project can be considerable.

After placing the order, progressing commences. In the case of equipment this will include:

- (1) Fabrication drawings for contractor approval.
- (2) Fabrication sub-orders for plate, bar, etc.
- (3) Fabrication sub-orders for motors, etc.
- (4) Fabrication shop progress.
- (5) Issuing release after inspection approval.
- (6) Confirming transport arrangements and advising construction site.

The work of the progressor is periodically presented as a schedule showing the state of each order on the project. This allows special treatment to be given to any supplier who may be back-sliding at a time when such action may be effective.

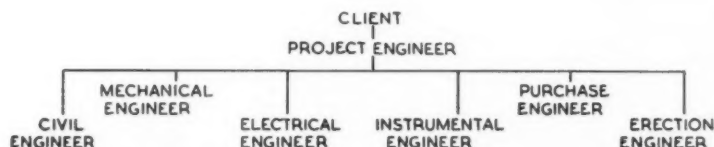


Fig. 3. Organisation of design team around project engineer.

### Inspection

The quality of materials and workmanship and the suitability of the fabricated equipment for its pressure duty is ensured by efficient inspection throughout manufacture.

The type of inspection applied will be based on the design codes used; the most commonly used are:

Lloyds Register of Shipping  
Associated Offices Technical Committee  
(A.O.T.C.)  
B.S. 1500: 1950  
B.S. 487: 1949  
B.S. 1113: 1951  
A.S.M.E. Section VIII, 1952  
A.P.I. A.S.M.E., 5th Edition, 1951

Inspection may include approval of maker, his works, material, manufacture, and testing of the final fabrication by radiography, hydrostatic and hammer tests. Test plates and weld coupons may be required and all welders should be certified by an approved authority.

Work may be subject to inspection by more than one authority chosen from:

- Contractor's inspector.
- Client's inspector.
- Client's insurance inspector.
- Lloyds registry.

Co-ordination of visits by inspectors will save valuable time and avoid extra charges from the fabricator who usually allows for single inspection.

As with purchasing, the inspection office builds up a considerable knowledge of fabricators' qualifications to carry out work and can provide valuable advice on quality before an order is placed.

### Erection

The engineer in charge of erection dreams of a project where all drawings material and plant are available on site on the commencement of a programme. This ideal situation, however, is rarely realised and site work usually commences before design is complete, calling for care in phasing the arrival of drawings and materials on site.

During the design stage of the project an overall programme will be developed and will take the form of a bar or Gantt chart covering: earthworks, piling, foundations and floors, buildings and structures, vessels and trucks, columns (fractionation), heat exchanger, pumps and compressors, instrumentation, electrical, pipework and fabrication, pipework and erection, insulation, and painting.

In addition to this overall programme, a detailed schedule showing the timing of each equipment item in



respect of delivery and erection within the overall programme is prepared, based on a logical sequence of erection operations in such a manner as to secure economic use of man-power and plant.

### Continuity

Once a site has been opened and facilities and staff deployed, costs continue to arise irrespective of work carried out. If costs are to be kept within the budget, continuity of work is essential. Site progress meetings are held with the object of anticipating snags and devising remedies.

Progress reports on a tight schedule should be on a weekly basis, as longer periods do not allow adjustment to be made rapidly enough. As construction is to some degree dependent on weather, a flexible attitude must be maintained to take advantage of opportunities to carry out work.

A typical bar chart is shown in Fig. 2 and further examples are given by Dugdale-Bradley in a recent paper<sup>3</sup>.

### Organisation

There are two main schools of thought about the organisation of projects. The first sees the project group as a team built around and responsible to the project engineer, and is exemplified in papers by Rose and Barrow<sup>1</sup> and by Miller<sup>4</sup>. This type of organisation may be shown as in Fig. 3.

The chief disadvantage of this type of organisation is its short life; teams are built up and broken down, and projects compete for the best engineers in the company.

The second school of thought sees a functional organisation of the companies' resources giving stability and permanence within these functional groups and can be shown as in Fig. 4. This system suffers from failure to identify the design team with the project and may render control impossible unless the project engineer has equal status with the functional heads; even then the individual engineer is subject to two loyalties.

In the writer's view, both systems

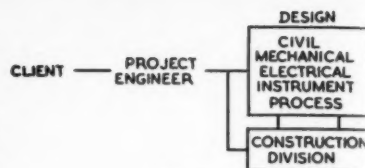


Fig. 4.

may be made to work well, if management has a clear understanding of the way they function and responsibilities are clearly defined. When organisations and programmes have been drawn up and materials ordered it is drive, initiative and flexibility of mind that will carry a project to its successful completion.

### REFERENCES

- <sup>1</sup>Rose and Barrow, 'Project Engineering of Process Plants.' Chapman & Hall, London.
- <sup>2</sup>K. M. Curwen, 17th Meeting of European Federation of Chemical Engineering, Institution of Chemical Engineers and Institute of Petroleum, London, June 1958.
- <sup>3</sup>J. O. Dugdale-Bradley, *Ibid.*
- <sup>4</sup>Miller, *Chem. Engg.*, 1956, (7), 185.

## Radiation Processing Plant for Britain

A big 'pilot' plant for the full-scale trial runs on the  $\gamma$  irradiation of materials is being built at the Wantage, Berks., radiation centre of the United Kingdom Atomic Energy Authority, and should be in operation by the end of the year. The plant, which is expected to be the first of its kind in the world, follows up research, which has been carried out for some years, on the useful employment of the large quantities of radioactive material which will become available as the nuclear power programme progresses. Firms which have been investigating the technical merit and commercial potentialities of irradiated materials will be able to have full-scale trials of such processes as the sterilisation of medical equipment and the disinfection of packaged products.

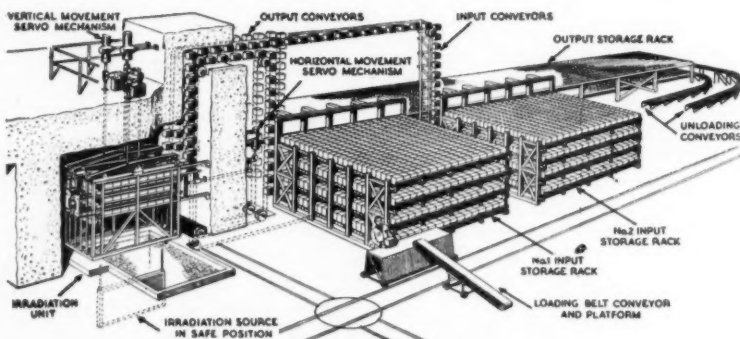
The plant covers an area of some 10,000 sq. ft., a tenth of this area being taken up by the irradiation cell, designed to house half a million curies of Cobalt 60, and its massive concrete shielding walls. The remainder of the plant includes storage for materials both before and after processing, and a well-integrated mechanical handling system. Packages, in units of about 1 cu.ft., will be handled continuously and automatically from bulk store through the equipment and into the treated-material store.

The U.K.A.E.A. do not reveal how much the plant will cost, but to ensure full utilisation of the capital investment, particularly of the source, which is continually radiating and decaying, the plant will operate 24 hr./day. The cell will be loaded initially with 150,000 curies, which will provide a throughput of 7 megarad-tons/day. As an example, in 24 hr. some 3 tons of medical products or imported animal fibres could be rendered sterile, since a sterilising dose is of the order of  $2\frac{1}{2}$  rads.

The plant is being built for the Technological Irradiation Group of the Isotope Research Division, Atomic Energy Research Establishment. De-

tailed design and construction of the mechanical handling and storage equipment is being carried out by the Owen organisation. The main companies within that group who are concerned are the parent company, Rubery Owen & Co. Ltd., and Electro-Hydraulics Ltd. The Owen design and manufacturing team is working in close collaboration with the Engineering Division at Harwell.

There is another plant approaching completion near Melbourne, Australia, which is to be operated by the Westminster Carpet Co., initially for the sterilisation of goat's hair used by the company in carpet making. It is a true production plant based on a design developed by the Technological Irradiation Group, Wantage.



Cut-away diagram of the Wantage irradiation plant.

# The Technology of ZIRCONIUM AND ITS ALLOYS

By D. R. Harries, B.Sc., Ph.D.

(Atomic Energy Research Establishment, Harwell)

**Part 2.—Corrosion behaviour in contact with various media; mechanical properties, including tensile and impact strength, creep properties, and effects of neutron irradiation**

## Corrosion resistance to acid and alkaline solutions

IN general the resistance of zirconium in acidic and alkaline media is excellent and comparable with that of tantalum. The potentialities for this metal in the chemical industry where severe corrosion problems arise would appear to be outstanding. Zirconium is not attacked by hydrochloric or nitric acids or by 50% NaOH or sulphuric acid at 100°C. Concentrated sulphuric acid and 75% phosphoric acid both attack zirconium at this temperature.

## Reactions with gases

With the common gases (except hydrogen, with which the reaction is appreciable at 300°C.) little significant attack occurs below 400°C. Above this temperature zirconium reacts with oxygen, nitrogen, carbon monoxide, carbon dioxide and water vapour, the rate increasing rapidly with rise in temperature. It is probable that only the inert gases are stable to zirconium at high temperatures. These excellent gettering characteristics of zirconium for the common gases have been a very troublesome feature in its development.

Recommended times for heating zirconium in air without serious surface oxidation are:<sup>1</sup> 24 hr. at 500°C., and 4 hr. at 700°C. Above 800°C. the oxide dissolves rapidly in the metal. Zirconium-aluminium alloys have exceptionally poor resistance to oxidation in air and a 1.48% aluminium alloy exhibits a distinct form of regular exfoliation (Fig. 2). A relatively higher scaling rate obtains in air than in oxygen or nitrogen alone, probably as a result of a tendency for the nitrogen to produce spalling and voluminous white deposits.<sup>1</sup> A comprehensive account of the oxidation of zirconium and its alloys in carbon dioxide has been given by O'Driscoll *et al.*<sup>22</sup> The oxidation of zirconium and some selected alloys in carbon dioxide at 500°C. and 8 atm. pressure is summarised in Table 5.

The oxidation rate depends on impurity content and degree of thermal



Fig. 2. Zirconium-1.48% aluminium alloy. Heated in air for 500 hr. at 450°C. (after Judge<sup>15</sup>)

cycling during oxidation. The effect of impurity content is of overriding importance at 500°C., but of minor importance at 400°C. Nitrogen contents up to 250 p.p.m. in the zirconium do not appear to have deleterious effects on oxidation resistance in CO<sub>2</sub> at elevated temperatures. However, carbon, titanium and aluminium are highly undesirable impurities. Binary additions of molybdenum, tungsten and copper in quantities up to 1.5 atm.% are beneficial in improving the oxidation resistance of zirconium in CO<sub>2</sub> and additions of niobium, tantalum and nickel are beneficial at the 0.25 atm.% level. The effect of pressure between 1 and 8 atm. at 500°C. is slight on the oxidation resistance, but

thermal cycling in CO<sub>2</sub> between room temperature and 800°C. at 1 atm. pressure accelerates the reaction.

The authors considered that the use of zirconium and its alloys in CO<sub>2</sub> cooled reactors operating at temperatures above 500°C. was not feasible.

## High-temperature water and steam

The reaction of zirconium and its alloys with water and steam at elevated temperatures can be described by the equation:

$$W = kt^n$$

where  $W$  = weight gain per unit area,  $t$  = time in days and  $k$  and  $n$  are constants.

Table 5. Oxidation of Zirconium and its Alloys in CO<sub>2</sub> at 500°C. and 8 atm. Pressure<sup>22</sup>

Material*	Weight gain (mg. sq.cm.) at — days								
	3	7	14	28	56	70	84	112	125
Arc-melted sponge zirconium	0.37	0.55	0.81	1.38	2.80	3.99	5.00	6.51	7.16
Arc-melted iodide zirconium	0.25	0.35	0.45	0.63	0.95	1.29	1.45	2.22	2.62
Arc-melted Zr 2	0.43	1.02	1.91	3.30	5.72	7.00	8.42	11.05	12.51
Zr + 1.5% Cu	0.37	0.58	0.79	1.09	1.84	2.21	2.57	3.36	3.75
Zr + 1.5% Mo	0.39	0.50	0.70	1.02	1.70	2.01	2.28	3.10	3.58
Zr + 1.5% W	0.35	0.52	0.73	1.06	2.15	2.47	2.84	3.91	4.47
Zr + 0.25% Nb	0.27	0.35	0.46	0.72	2.00	2.57	3.10	4.14	4.59
Zr + 0.25% Ta	0.30	0.47	0.74	1.08	1.83	2.31	2.88	4.00	4.47
Zr + 0.25% Ni	0.28	0.37	0.49	0.76	1.91	2.46	3.01	4.19	4.73
Zr + 0.25% Sn	0.27	0.41	0.61	1.08	2.61	3.16	3.67	4.70	5.50

\*Origin of alloys—sponge zirconium

During the initial period of this reaction, when  $n$  is less than 0.5, the rate law is parabolic and a thin adherent film, which is black or exhibits interference colours, forms on the surface and provides some protection. Later a white non-adherent corrosion product (monoclinic  $\text{ZrO}_2$ ) begins to form, and the new rate law is believed to be linear ( $n = 1$ ). The point at which the rate law becomes linear has been termed 'breakaway.'

The length of the initial period of low corrosion rate depends strongly on impurities, the most injurious being nitrogen, carbon, aluminium, titanium and, to a lesser extent, hydrogen.<sup>15</sup> The effect of nitrogen content on the corrosion resistance of iodide zirconium in 315°C. water is shown in Fig. 3. With more than 0.004% nitrogen the samples break down rapidly.

The surface condition of the zirconium also governs the length of the initial period of low corrosion rate. Pick-up of nitrogen on the surface and in the metal immediately below it during heating in air at high temperatures, as in fabrication, is harmful and must be removed. The corrosion rate is also influenced by mechanical operations on the surface such as machining and abrading, which give rise to a layer of disturbed metal at the surface and for an appreciable depth under it.<sup>7</sup> The disturbed layer exhibits a more rapid corrosion rate than does the bulk metal and hence must be removed before exposure to corrosion.

Iodide zirconium of the highest purity has very good corrosion resistance in high-temperature water. However, in general, its corrosion resistance is not adequate in that it is not very reproducible; further, it has low strength and is expensive. These disadvantages of the iodide zirconium provided the incentive which led to the development of the sponge-base *Zircaloy* series of alloys in the U.S.A. The addition of tin remarkably increases the corrosion life of impure zirconium; however, the corrosion resistance of pure zirconium is reduced. Tin does not exert a complete beneficial effect unless iron, nickel or chromium are also present.<sup>23</sup>

*Zircaloy 1* did not come up to expectations as regards corrosion resistance. *Zircaloy 2* meets the corrosion resistance required and its corrosion resistance approaches, and under certain conditions exceeds, that of the purest unalloyed zirconium. *Zircaloy 3* was developed to provide corrosion resistance at higher temperatures than are possible with *Zircaloy 2* and exhibits

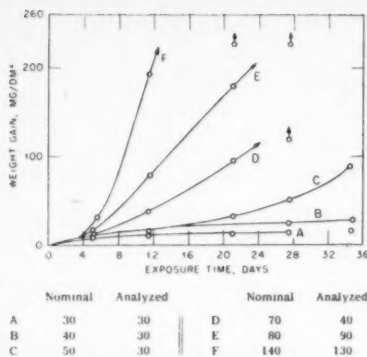


Fig. 3. Effect of nitrogen content on the corrosion resistance of iodide zirconium in 315°C. water. The nitrogen content in p.p.m. is tabulated above (Lustman and Kerze<sup>15</sup>)

lower post-breakdown corrosion rates than *Zircaloy 2*.

The weight gain-time curves for *Zircaloy 2* exposed to high-temperature water and steam are shown in Fig. 4 and the empirical equations describing its corrosion behaviour in Table 6.

Maximum nitrogen and carbon contents of 80 and 270 p.p.m. respectively have been specified for American *Zircaloy 2* for applications requiring optimum high-temperature water corrosion resistance.<sup>25</sup> Conflicting evidence has been presented by Flint<sup>26</sup> in that 220 p.p.m. nitrogen can be tolerated in British *Zircaloy 2* without

obvious acceleration of attack in 320°C. water in tests of up to 230 days' duration. It appears from this that the influence of a harmful impurity such as nitrogen may depend on the presence of other impurities producing a favourable effect.

*Zircaloy 2* appears to be less sensitive than unalloyed zirconium to surface preparation. Flint<sup>26</sup> observed that mechanical polishing of the surface is equally as efficient in minimising corrosion effects as the conventional  $\text{HNO}_3$ :HF pickle. Also, Cox<sup>27</sup> has established that the use of *Zircaloy 2* in the machined state gives similar corrosion results to those expected for pickled specimens.

Recently attempts have been made to develop zirconium alloys which have good corrosion resistance in water and steam at higher temperatures than are permissible with *Zircaloy 2* and 3. Russian results of corrosion tests in 350°C. water and 400 and 450°C. steam are given in Table 7.

At 350°C. the corrosion rates of all the alloys are comparable. At 400°C. and 450°C. the *Ozhennite 0.5* alloy has equal if not better corrosion resistance than the *Zircaloy* type.

*Zircaloy 2* and 3 withstand less than one day in 480°C. steam at 1,500 p.s.i. before spalling begins and investigations made in the U.S.A. have aimed at developing alloys which will with-

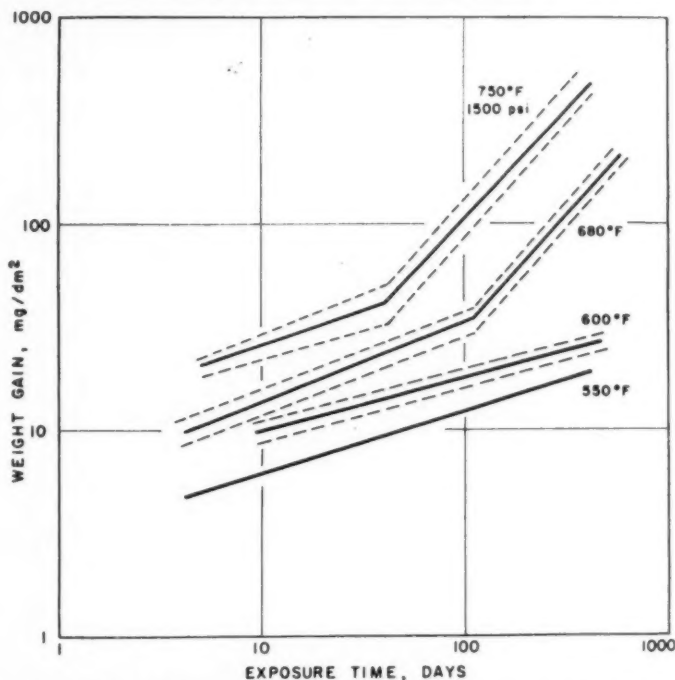


Fig. 4. Weight gain-time curves for 'Zircaloy 2' exposed to high-temperature water and steam (after Thomas and Forscher<sup>24</sup>)



stand attack in steam at this temperature.<sup>29</sup> Nickel in concentrations as low as 0.2 wt.% improves the resistance of zirconium to the extent that these binary alloys survive two months in 480°C. steam before spalling begins. The corrosion resistance is dependent on the heat-treatment, an anneal at 800°C. followed by air cooling giving the best properties. Chromium gives similar results (in concentrations of 1 wt.%) to nickel. Iron (1 and 3 wt.%) gives some protection, but tin is deleterious to the corrosion resistance in 480°C. steam, although it confers good corrosion resistance in high-temperature water.

### Liquid metals

Although investigators of the corrosion properties of zirconium and its alloys have tended to concentrate on its behaviour towards water and steam at elevated temperatures, there has been more emphasis recently on the corrosion in liquid metals because of the possibility of developing high-temperature zirconium alloys for reactors cooled by liquid metals.

Zirconium is rapidly attacked or completely dissolved in liquid bismuth and bismuth alloy eutectics and also by lead. However, zirconium and its alloys appear to be resistant to attack by oxygen-free sodium at 500°C. under static and dynamic conditions, but the presence of oxygen in the sodium has a very corrosive effect.<sup>30</sup>

The resistance of zirconium to attack by liquid metals is summarised in Table 8. The resistance to attack is rated as good, limited and poor for rates of attack of <1, >1 and <10, and >10 mil p.a.

### Hardness, tensile and impact

The mechanical properties of zirconium and its alloys depend greatly on the purity, particularly with respect to oxygen, nitrogen and hydrogen. These elements go into interstitial solid solution in the zirconium, and both oxygen and nitrogen have a marked strengthening effect on the room temperature tensile properties. Hydrogen has little effect on the tensile properties above room temperature. The effects of oxygen and nitrogen on the room temperature hardness and tensile properties of electron bombardment melted iodide zirconium, rolled to strip 0.020 in. thick and annealed at 750°C. for 2 hr., are given in Table 9.

Hydrogen is generally present in zirconium in amounts of 30 p.p.m. but larger amounts may be introduced during fabrication and corrosion. Hydrogen increases the ductile-brittle

transition temperature and lowers the energy-absorbed values in notched-bar impact tests. This is exemplified in Fig. 5 which shows the effect of hydrogen on the impact strength of arc-melted iodide zirconium-1.5% tin alloy.

Mudge<sup>33</sup> has shown that most zirconium contains sufficient hydrogen to render it susceptible to embrittlement. To develop embrittlement it is necessary to heat to above 315°C. and then cool at a rate slower than a critical rate to a temperature below 260°C. The critical cooling rate depends on the hydrogen content of the material. For example, water-quenching material containing 50 p.p.m. hydrogen from 315°C. is sufficient to suppress precipitation of ZrH. With hydrogen contents of about 100 to 500 p.p.m.,

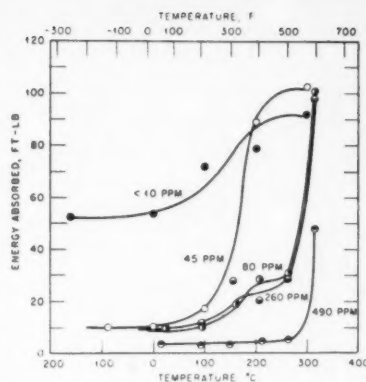


Fig. 5. Effect of hydrogen on the impact strength of an arc-melted iodide zirconium-1.5 wt.% tin alloy (after Mudge<sup>33</sup>)

Table 6. Empirical Equations for Corrosion Behaviour of 'Zircaloy 2'<sup>24</sup>

Temperature, °C.	Pressure, p.s.i.	Equation W in mg./sq.dm.	Time (t) days
288	750	$W = 0.50t^{0.30}$	Up to 1,150 After 1,150* Up to 112 After 112 Up to 41 After 41
316	1,553	$W = 0.74t^{0.26}$	
360	2,705	$W-34 = 0.065(t-1150)$	
		$W = 0.76t^{0.38}$	
400	1,500	$W-34 = 0.37(t-112)$	
		$W = 1.10t^{0.32}$	
		$W-41 = 1.27(t-41)$	

\* Estimated

Table 7. Corrosion Resistance of Zr Alloys in High-temperature Water and Steam<sup>28</sup>

Alloy	Weight gain in mg./sq.dm. at ...		
	350°C. 5,500 hr.	400°C. 4,000 hr.	450°C. 3,000 hr.
Zr + 1% Nb .. .. .	50 to 175	270 to 400	630 to 900
Ozhennite 0.5 (0.2% Sn; 0.1% Fe; 0.1% Nb; 0.1% Ni) .. .. .	50 to 100	150 to 200	400 to 500
Ozhennite 1 (1.0% Sn, Fe, Nb and Ni)	50 to 100	150 to 200	550 to 650
Zircaloy type 0.5 to 1.0% Sn; 0.3% Ni; 0.2% Fe .. .. .	50 to 100	150 to 200	320 to 600

Table 8. Corrosion of Zirconium by Liquid Metals<sup>31</sup>

(U = Unknown, G = Good, L = Limited, P = Poor, \* = degree of resistance at the melting point)

Liquid metal		Na, K, Na-K	Li	Mg	Zn	Cd	Hg	Al	Ga
M.pt.	°C.	-12.3 to 98.3	186	651	419.5	321	-38.8	660	29.8
Zr	800	U	L	U	U	U	U	U	U
	600	G	L	P*	U	U	P	U	P
	300	G	G	U	U	U	U	U	L
Liquid metal		In	Tl	Sn	Pb	Bi-Pb	Bi-Pb-Sn	Sb	Bi
M.pt.	°C.	156.4	303	231.9	327	125	97	630.5	271.3
Zr	800	U	U	U	L	U	U	U	P
	600	U	U	U	L	L	L	U	P
	300	U	U	G	G	G*	G	U	U

water quenching is insufficient and a faster cooling rate would be necessary to avoid embrittlement. Mudge concluded that as little as 10 p.p.m. hydrogen in zirconium is sufficient to cause noticeable embrittlement in the quenched and aged condition.

The mechanical properties of zirconium and its alloys are also affected by prior history. The tensile properties of *Zircaloy*s 2 and 3 in various conditions are given in Table 10.

Unalloyed zirconium has poor high-temperature strength and it is similar to most other metals in the pure state in that it requires alloying to develop satisfactory high-temperature properties. *Zircaloy*s 2 and 3 show improvements in high-temperature strength over unalloyed zirconium; further, it has been demonstrated<sup>35</sup> that additions of 0.35 w/o beryllium to *Zircaloy* 3 causes an increase in elevated temperature strength with corrosion resistance in 360°C. water equal to that of *Zircaloy* 2.

The tensile properties of zirconium alloys at room and elevated temperatures have been detailed by Miller,<sup>1</sup> but the yield and ultimate tensile strengths at 500°C. of zirconium and a selected series of binary alloys are given in Table 11.

Tensile tests on ternary and quaternary zirconium alloys have indicated that ultimate tensile strengths up to about 150,000 and 100,000 p.s.i. at room temperature and 500°C. respectively, with elongations in the range 2 to 20%, are possible. Results on some of these alloys are given in Table 12. The alloys were induction melted, extruded into rods and rolled flat at 790°C. All the samples were held 3 hr. at the solution treatment temperature, water-quenched to room temperature, aged for the times and at the temperatures shown, then water-quenched to room temperature.

## Creep

Creep results on zirconium and its alloys are relatively scarce and wide differences have been observed between sponge-base and iodide-base materials. Also, from the limited results available, it appears that the fabrication and annealing history is just as important in affecting the creep properties as in the case of the tensile properties. The results of creep and stress-rupture tests on arc-melted sponge zirconium containing about 2% hafnium in the temperature range 300 to 550°C. are summarised in Table 13. The creep tests were conducted in an

**Table 9. Effects of Oxygen and Nitrogen on Room-temperature Hardness and Tensile Properties of Iodide Zirconium<sup>32</sup>**

Weight, %	Mean hardness, V.P.N. 10 kg. load	L. of P., tons/sq.in.	U.T.S., tons/sq.in.	Elongation, in 1.5 in., %
O <sub>2</sub>				
0.02	112	9.8	13.3	17.4
0.06	144	10.8	18.3	17.4
0.15	170	15.9	22.1	8.1
0.20	206	20.0	23.4	2.8
0.55	229	21.5	23.2	1.7
N <sub>2</sub>				
0.008	176	—	13.0	17.6
0.030	221	10.4	20.5	14.7
0.044	225	14.5	24.5	10.8
0.069	246	18.5	28.1	15.0
0.120	260	28.3	36.4	12.0

**Table 10. Effect of Prior History on Room- and Elevated-temperature Tensile Properties of 'Zircaloy' 2 and 3<sup>34</sup>**

	0.2% Yield strength × 10 <sup>3</sup> p.s.i.			Ultimate tensile strength × 10 <sup>3</sup> p.s.i.			Elongation, %			Reduction in area, %		
	R.T.	250°C.	350°C.	R.T.	250°C.	350°C.	R.T.	250°C.	350°C.	R.T.	250°C.	350°C.
<i>Zircaloy</i> 2												
(a)	83.0	55.2	51.0	95.0	60.8	53.6	8.0	9.9	8.0	30	46	51
(b)	44.0	19.4	16.3	68.8	36.0	30.9	30.0	25.0	29.6	48	54	75.5
(c)	83.0	46.6	41.0	95.0	51.0	42.6	9.0	8.95	7.9	44	55	68
(d)	77.8	57.8	52.8	87.5	61.8	57.2	9.0	8.4	7.6	42	64	66
<i>Zircaloy</i> 3												
(a)	88.2	55.8	43.6	98.4	59.6	47.6	8.0	9.4	13.9	34	50	62
(b)	44.8	16.4	14.1	71.8	33.8	25.6	29.0	30.6	35.4	42	64	75.5
(c)	90.2	45.0	35.0	102.0	47.6	36.1	8.3	11.9	8.67	35	48	64
(d)	103.0	58.2	50.8	110.0	60.1	52.8	10.5	8.3	6.9	46	63.5	66

(a) 'As received'; cold-swaged ~15%

(b) Base annealed in vacuum for 20 hr. at 750°C.

(c) Base annealed + 10% cold-worked (swaged)

(d) β-annealed at 1,000°C. for 4 hr., quenched and cold-swaged 10%

**Table 11. Yield and Tensile Strengths of Zr and Some Alloys at 500°C.<sup>36</sup>**

Alloy	Y.S. (10 <sup>3</sup> p.s.i.)	U.T.S. (10 <sup>3</sup> p.s.i.)
Unalloyed Zr . .	8.8	14.3
Zr + 2% Al . .	32	46
Zr + 1.3% Mo	49	74
Zr + 2.2% Nb	35	43
Zr + 6.4% Ta	27	34.5
Zr + 10.4% Ti	41	58
Zr + 4.8% Sn	24	32

**Table 12. Tensile Properties of Ternary and Quaternary Zirconium Alloys at Room Temperature and at 500°C. in Argon<sup>37</sup>**

Alloy	Solution temp., °C.	Ageing data		R.T.		500°C.	
		Time, hr.	Temp., °C.	U.T.S., p.s.i.	Elong. in 2 in., %	U.T.S., p.s.i.	Elong. in 2 in., %
Zr-5.45% Mo-1.81% Al	760	40	600	108,000	3.5	104,000	10.2
Zr-5.32% Nb-1.7% Al	860	40	600	155,000	4.7	83,500	10.9
Zr-2.87% Mo-3.10% Nb-1.80% Sn	750	40	600	112,500	10.9	56,200	12.5
Zr-4.85% Ti-4.85% Mo-1.90% Sn	750	40	500	119,000	1.98	80,000	20.3
Zr-3.06% Ta-1.9% Sn	950	40	600	99,500	34.5	48,000	18.8
Zr-4.59% Ta-2.02% Sn	950	40	600	117,000	9.37	54,700	9.3

Table 13. Creep Rupture Data on Arc-melted Zirconium Containing 2% Hf<sup>32</sup>

Temp., °C.	Stress, tons/sq.in. § p.s.i.*	Time to reach specific % creep strain in hours								Minimum creep rate, in./in./hr.	Final strain, %	Duration, hr.
		0.05	0.1	0.2	0.5	1.0	2.0	5.0	10.0			
300	10.0§							3	6	$3.7 \times 10^{-3}$	37	28†
300	9.0§						1			$2.5 \times 10^{-7}$	2.705	5,000‡
300	8.5§				2					$1.0 \times 10^{-6}$	0.72	1,440†
350	8.7§							55	210	$3.2 \times 10^{-4}$	39	431†
350	8.5§					11	455	1,267		$19 \times 10^{-6}$	32	2,098‡
350	7.4§				354	958				$10.5 \times 10^{-6}$	35	4,769‡
400	7.5§					7	22	72	97	$6.3 \times 10^{-4}$	42	178‡
400	6.5§					5	12	55	115	—	52	250†
500	1,500*	113	280	610	1,609	—				$3.1 \times 10^{-6}$	0.61	1,986†
500	2,500*	4	8	30	104	268				$14 \times 10^{-6}$	2.209	986†
550	500*	284	555	980	—	—				—	0.253	1,124†
550	1,500*	5	11	28	95	276				$24 \times 10^{-6}$	1.061	306†
550	2,000*	—	4	7	22	68				$43 \times 10^{-6}$	2.46	315†

† Billet analysis: 0.11% O<sub>2</sub>; 0.009% N<sub>2</sub>; 0.003% H<sub>2</sub>; 0.03% C  
 ‡ Billet analysis: 0.23% O<sub>2</sub>; 0.016% N<sub>2</sub>; 0.003% H<sub>2</sub>; 0.05% C

Table 14. Creep Results on 'Zircalloys 2 and 3'<sup>34</sup>

Material	Condition	Test temp., °C.	Stress, 10 <sup>3</sup> p.s.i.	Plastic strain on loading, %	Minimum creep rate, in./in./hr.	Rupture strain, %	Time to rupture, hr.	Reduction in area, %
Zircaloy 2	As received (Cold-swaged ~15%)	250	59.0	0.27	$8.3 \times 10^{-4}$	7.64	38.2	45.7
			56.0	0.23	$7.1 \times 10^{-5}$	7.56	468	43.9
		350	51.3	0.50	$2.3 \times 10^{-2}$	14.1	2	53.6
			45.0	0.26	$3.5 \times 10^{-3}$	14.0	14.5	58.9
			41.0	0.05	$5.0 \times 10^{-5}$	19.2	1,087	57.0
	Base-annealed in vacuum for 20 hr. at 750°C.	37.5	0.02	$1.6 \times 10^{-5}$	>15.4	>3,525	—	—
		250	32.0	4.67	$5 \times 10^{-2}$	26.6	2.5	71.6
		350	27.0	5.0	$6.2 \times 10^{-4}$	21.55	88	66
	Base-annealed + cold-swaged 10%	250	46.0	0.08	$1.15 \times 10^{-3}$	6.18	14	60
	β-annealed at 1,000°C. for 4 hr.; quenched and cold- swaged 10%	250	57.5	0.25	$1.6 \times 10^{-4}$	4.9	69	54
350	51.0	0.06	$1.9 \times 10^{-4}$	7.86	287	52		
Zircaloy 3	As received (cold-swaged ~15%)	250	53.0	0.20	$4.8 \times 10^{-3}$	10.47	8.4	50
			50.0	0.08	$5.2 \times 10^{-4}$	13.7	105.5	52
			47.0	0.06	$\sim 4 \times 10^{-5}$	18.3	2,680	54
		350	40.0	0.3	$2.3 \times 10^{-2}$	13.74	2.8	58
			36.0	0.025	$3.2 \times 10^{-3}$	21.3	31	60
			25.0	0.006	$1.72 \times 10^{-5}$	>17.5	>4,026	—
	Annealed in vacuum for 20 hr. at 750°C.	250	29.0	3.58	$4.9 \times 10^{-2}$	30.6	3.5	62
		350	25.0	2.08	$3.4 \times 10^{-3}$	33.6	57	63
	Annealed + cold-swaged 10%	350	22.0	3.53	$7.8 \times 10^{-3}$	39.06	24.5	—
		350	18.0	3.48	$5.9 \times 10^{-4}$	50.2	370	73
	β-annealed at 1,000°C. for 4 hr.; quenched and cold- swaged 10%	250	41.0	0.06	$2.3 \times 10^{-3}$	7.3	6.0	—
			36.0	0.00	$3.5 \times 10^{-5}$	7.6	506	—
		350	57.5	0.14	$1.0 \times 10^{-4}$	8.37	253	—
			45.0	0.00	$4.6 \times 10^{-4}$	18.38	69	66

inert atmosphere on samples annealed at 700°C. for 20 hours after extrusion.

As a consequence of the poor high-temperature properties of zirconium, improvement in creep resistance has been sought in alloys of the metal. The creep properties of Zircalloys 2 and 3 are given in Table 14. Although their tensile properties are quite similar (see Table 10), Zircaloy 2 has much better creep properties than Zircaloy 3. The difference is magnified at lower second-stage creep rates and/

or higher temperatures. The stress-rupture properties of Zircaloy 2 at temperatures in the range 150 to 500°C. are given in Table 15.

Studies carried out at the Admiralty Materials Laboratory have aimed at developing alloys which have higher creep resistance than zirconium and Zircaloy 2. The creep tests have been made mainly on graphite-melted material at 300°C. in air and at 450°C. and 600°C. in argon.<sup>39, 40, 41</sup>

At 300°C. and 20,000 p.s.i. the best

group of alloys are the 'as-extruded' zirconium-tin alloys. The creep resistance increased with tin content, there being only a total creep strain of  $5 \times 10^{-5}$  in./in. in a 6.7% tin alloy after 4,000 hr. The zirconium-tin alloys with the Zircaloy 2 minor additions (iron, chromium and nickel) give lower creep deformation than their binary tin counterparts. The creep properties of arc-melted zirconium and 'as-extruded' graphite-melted alloys are given in Table 16.



Tests at 300°C. have been extended to stresses of 30,000 p.s.i. The 6.5% tin binary alloy shows very good creep resistance under these conditions, the creep strain in 10,000 hr. being  $30 \times 10^{-6}$  in./in. The creep deformations of all the other alloys were much higher under these conditions.

At 450°C. and 6,000 p.s.i., the best alloy tested to date is the 6.5 w/o tin binary alloy in the aged (1,030 hr. at 450°C.) condition. This shows a deformation of  $40 \times 10^{-6}$  in./in. in 1,500 hr. compared with  $80 \times 10^{-6}$  in./in. in the same time for the alloy in the 'as-extruded' condition.

At 600°C. and 3,000 p.s.i. an 'as-extruded' 1.48 w/o aluminium binary alloy shows the minimum creep defor-

**Table 15. Stress-rupture Properties of 'Zircaloy 2'**<sup>38</sup>

Temperature, °C.	Stress to produce rupture in indicated time (10 <sup>3</sup> p.s.i.)		
	1 hr.	10 hr.	100 hr.
<i>Annealed sheet, transverse direction</i>			
150	35.2	32.5	30.0
230	28.0	26.0	24.0
345	22.2	22.0	21.8*
425	21.3	19.0	16.8
500	17.7	15.1	11.4
<i>Cold-worked sheet, transverse direction</i>			
150	73.0	70.5	68.0
230	63.0	60.5	58.0
345	50.0	46.0	43.0
425	38.0	34.0	29.0
500	27.5	21.5	14.5

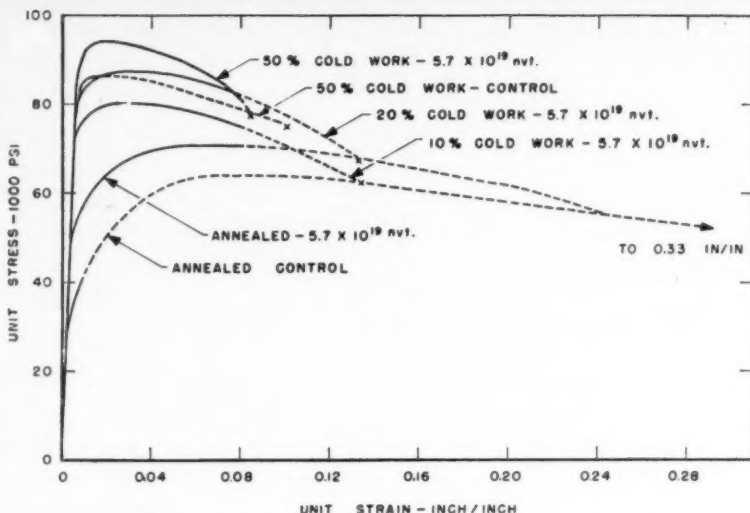
\*Estimated

**Table 16. Creep Properties of Zr and Some Alloys at 300°C. in Air**<sup>41</sup>

	Stress, p.s.i.	Total creep strain in 4,000 hr. $\times 10^{-5}$ in./in.
Arc-melted Zr ..	14,000	700
Zr + 1.64 w/o Sn	20,000	270
Zircaloy 2 ..	20,000	195

**Table 17. Effects of Neutron Irradiation on Tensile Properties of 'Zircaloy 2'**<sup>44</sup>

	U.T.S. 10 <sup>3</sup> p.s.i.	0.2% P.S. 10 <sup>3</sup> p.s.i.	Elongation in 1 in. %
<i>Annealed</i>			
Control ..	68.4	44.1	23.0
Irradiated	79.4	70.0	15.4
<i>50% cold-worked</i>			
Control ..	98.3	79.6	19.5
Irradiated	114.5	104.5	9.2



**Fig. 6. Typical stress-strain curves for unirradiated and irradiated arc-melted zirconium (after Kemper and Kelly<sup>42</sup>)**

mation of  $1,600 \times 10^{-6}$  in./in. in 2,000 hr. However, this alloy has poor oxidation resistance.

#### Effects of neutron irradiation

Neutron irradiation has a marked effect on the mechanical properties of zirconium and Zircaloy 2. Radiation damage in annealed materials is generally manifested as increases in yield strengths and, to a lesser extent, in ultimate tensile stresses and reductions in ductility in tensile tests; increases in ductile-brittle transition temperatures in notched-bar tests and increases in hardness. The damage is due to the fast neutron displacement of atoms from their equilibrium positions, creating vacant lattice sites and interstitial atoms and the subsequent interaction of these point defects with dislocations.

Kemper and Kelly<sup>42</sup> have investigated the effects of thermal neutron doses of  $5.7 \times 10^{19}$ ,  $1.5 \times 10^{20}$  and  $2.4 \times 10^{20}$  n cm.<sup>-2</sup> at 50 to 60°C. on the hardness and tensile properties of arc-melted sponge zirconium in the annealed and 10, 20, 30, 40 and 50% cold-worked conditions.

The maximum hardness increase was observed in the annealed material which increased 20 points Rockwell G (50 R<sub>G</sub> to 70 R<sub>G</sub>). The hardness increase was progressively less with increasing prior cold work with the 50% cold-worked material increasing 10 points Rockwell G (65 R<sub>G</sub> to 75 R<sub>G</sub>). The hardness appeared to approach a saturation level at the higher neutron exposures and was essentially independent of cold work.

The most pronounced effect of irradiation on the tensile properties

was noted in the yield strength. A maximum increase of 65% occurred in the annealed material. The change in yield strength was also less for the material with prior cold work. In contrast, a more uniform increase in ultimate tensile strength and decrease in ductility resulted independent of the cold-work level. The changes in these properties were not drastic and the material still behaved in a ductile manner. The effect of increased exposure was only slight and additional irradiation at this temperature would not be expected to produce further deleterious changes in properties. The effects of neutron irradiation on the tensile properties are exemplified in Fig. 6.

Makin and Minter<sup>43</sup> obtained evidence contrary to the above in that a thermal neutron dose of  $5.1 \times 10^{19}$  n cm.<sup>-2</sup> at about 100°C. caused a reduction in the yield stress of zirconium containing 2% hafnium in the hard drawn condition at all test temperatures in the range 20 to 200°C. However, the ultimate tensile strength and elongation values were increased by irradiation. The authors suggested that in cold-worked material the effects of irradiation appear to be, in general terms, to anneal out a part of the cold-work damage, replacing it by irradiation damage.

The effects of neutron irradiation on the room temperature tensile properties of annealed and 50% cold-worked Zircaloy 2 have been reported by Kemper and Zimmerman.<sup>44</sup> The tensile specimens were irradiated in water at 40 to 60°C. to an estimated

(Concluded on page 378)

## Nuclear Notes

### Giant manipulator for nuclear rocket project

Another 'biggest ever' from the U.S.A.—this time a giant, remotely controlled mechanical arm for remote-control manipulation, designed to lift up to 5,000 lb. but with a dexterity and precision of control that enables it to perform intricate tasks.

A product of General Mills, the manipulator was purchased by the University of California's Los Alamos Scientific Laboratory for use in connection with 'Project Rover,' a study of the feasibility of developing nuclear propulsion for rockets. Research in the project is conducted at Los Alamos, New Mexico, and reactors are tested at the Nevada test site. There, after reactors have been operated, they are transported to a heavily shielded building for disassembly by remote control, since radioactivity levels are high. After disassembly, the reactor components can be studied to learn the effects of testing.

The mechanical arm is remotely operated from a control console positioned in a safe location outside the area, operator viewing being accomplished through a window or periscope, or by closed-circuit television.

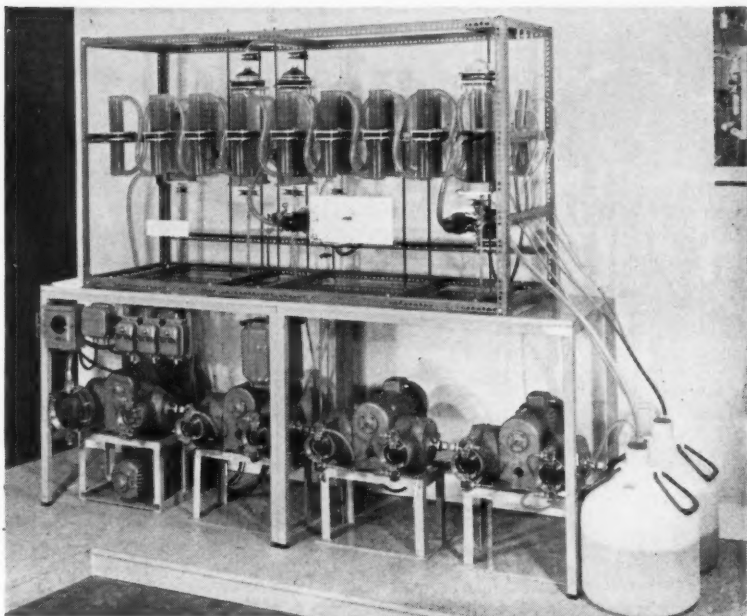
### Nuclear fuel separation

A bench-scale purifier for atomic reactor fuels, with a capacity of refining 5 tons of uranium p.a., has been designed by chemists of the atomic laboratory of Asea Co., Sweden. The apparatus consists of a chain of series-coupled tubes containing perforated bottom plates. Uranium or plutonium is separated from impurities by means of extraction with organic solvents.

In operation, the apparatus has a striking resemblance to medical apparatus like the 'artificial kidney' and the 'heart-lung machine' since the two liquid solutions, the extraction medium and the solution to be purified pass through the column elements in rhythmic pulsation.

### Privately owned reactor goes critical

A preliminary run with the *Jason* training and research reactor, built near Slough, Bucks., by the Hawker Siddeley Nuclear Power Co. as a private venture, and started up right on schedule on September 30, gave expectations that the calculated performance will be fully justified. Claimed to be the first small British training



Part of Asea display at Royal Institute of Technology, Stockholm, showing new atomic fuel purifier.

and research reactor specially designed for university, medical and other research centres, *Jason's* output is 10 kw. and it has a consumption of less than 1 g. of uranium fuel annually.

The reactor is based on the design of the *Argonaut* at the Argonne National Laboratories, U.S.A. It is light-water moderated and cooled and has graphite reflectors and a thermal column embodying 20 experimental holes. A water tank for shielding experiments is also included. The maximum flux at a power level of 10 kw. is about  $1.5 \times 10^{11}$  neutrons/sq.cm./sec. Other versions of *Jason* are available and Hawker Siddeley are developing extensions to the range.

### Tracers test air-filter efficiency

A radioactive tracer has been used successfully, in the U.S.A., in experiments to determine precisely the operation and efficiency of a special air filter for use on a locomotive braking system. On diesel locomotives, the directly connected air compressor which furnishes the air supply for the brake system runs at high speed and high temperature, and fine particles of the lubricating oil, less than 1 micron in diam., are carried into the compressed-air system. Not only are these fine particles difficult to filter, but they

form varnish-like deposits in critical parts of the air-brake equipment.

Westinghouse Air Brake Co. needed a filter to overcome this problem, but were faced with the difficulty of lengthy testing procedures. They called in the help of Nuclear Science & Engineering Corporation and a procedure was worked out by which a radioactive tracer, antimony 124 in the form of triphenylstibine, would be added to the lubricating oil so that the minute particles in the air stream could be detected. A 2 in.  $\times$  2 in. thallium-activated sodium iodide crystal was used as the detector. By the use of the radio-tracer technique it was possible to obtain in a relatively short time information which had previously been obtainable only from prolonged tests, or not at all.

### New light on closed-circuit television

The quality of a television picture is dependent on a number of factors, but in particular on the intensity and direction of the object lighting with respect to the camera and on the amounts of light reflected by different parts of the object. Some complicated problems are involved in providing lighting for television cameras on a nuclear-reactor charge machine, as is

shown by experiments recently carried out in the laboratories of the General Electric Co. Ltd. at Wembley, Middlesex. These experiments formed part of the development work on the charge machine for the Hunterston nuclear power station, which is being built by the company for the South of Scotland Electricity Board. At Hunterston the charge machine will handle a complete stack of 10 fuel elements in one operation, each operation being carried out in a series of automatically sequenced groups. The movements will be monitored by instruments on the remote-control desk, but a visual check will be provided by means of closed-circuit television.

Owing to the complexity of the mechanical system and the large number of operations to be considered, the positions of the cameras, and the positions and intensities of the lamps, could not be deduced reliably just by calculation from the drawings. But

they had to be determined before fabrication of the pressure vessel for the machine. A full-scale wooden model of the operating mechanisms concerned was built and operations such as removing and stowing the standpipe door and concrete shield plug, locating the charge tube, inserting and withdrawing fuel elements, could all be simulated by manual operation of parts of the model. A comprehensive series of tests was then carried out to determine the most suitable positions of lamps and cameras.

An important conclusion from the experiments has been that these positions are quite critical if the best results are to be obtained. Certain of the mechanisms are masked by others and special pointers must be attached to them to show their movement. During the tests it was found that the two-dimensional presentation of an essentially three-dimensional object sometimes produced the optical illu-

sion of 'inversion,' that is, a nearer edge sometimes appeared to be further away. A solution was found by painting contrasting stripes on some parts of the mechanisms to accentuate their shapes and emphasise their true perspective.

The use of paints can improve picture quality, but care must be taken in their selection. One reason is that the inside of the machine effectively forms part of the coolant-gas circuit, when it is connected to the reactor, and there are severe restrictions on the types of material that may be introduced into this circuit. In addition, the radiation intensity due to spent fuel elements withdrawn into the machine will be very high, and it is necessary for the paint not to be affected by this.

With the arrangement finally chosen it was found possible to obtain good pictures with an illumination of 10 to 40 lumens/sq.ft.

## INDUSTRIAL PUBLICATIONS

**Catalysts.** The latest Girdler catalyst catalogue (GC2000) includes brief descriptions of a number of commercially tried catalysts, intended to suggest applications for which they can be used. In some instances, ranges of pressures, temperatures, space velocities, etc., are mentioned. Another section of the catalogue describes a number of catalysts which are in various stages of development and which are available to prospective customers for further investigation. As well as a description of the Girdler customer services and a list of technical literature, the catalogue has an index to simplify the finding of the catalysts available for various uses. Copies of the catalogue are available from the Anglo-Continental Fuller's Earth Co. Ltd., 1 Lloyds Avenue, London, E.C.3.

**Bellows,** and their application to stainless-steel expansion joints and other industrial uses, are discussed in an illustrated, 10-page brochure from Teddington Aircraft Controls Ltd., Ammanford, Carmarthenshire. An introductory section provides a guide to potential bellows users, particularly to designers of special equipment involving the use of bellows. Expansion joints for pipelines and ducts are then dealt with and there is a useful glossary of terms. Hinged and articulated bellows units are discussed, as are also the special problems of constructing rectangular and large-diameter assemblies.

**Automatic stoker.** An illustrated pamphlet describes an automatic coal stoker in which the coal is pre-burnt in the water-cooled combustion chamber and the hot gases are directed into the boiler to which the stoker is fitted. Strongly caking coals can be burnt and small coal, although, in order to guarantee maximum efficiency, the amount of fines below  $\frac{1}{8}$  in. should not exceed 35%, the moisture-content limit being around 15%. These and other details are described in the pamphlet, available from G.W.B. Furnaces Ltd., P.O. Box No. 4, Dibdale Works, Dudley, Worcs.

**Knitted mesh.** New catalogues of *KnitMesh* products include one which gives a description of all the materials, sizes, etc., in which this material can be obtained. Another catalogue and price list shows *KnitMesh* for use in demisters and entrainment separators, a relatively new application. A pamphlet on *KnitMesh* in industry shows some of the many fields in which it can be used and developed. The catalogues are issued by KnitMesh Ltd., 36 Victoria Street, London, S.W.1.

**Air sampling.** Several methods of determining the amount and size distribution of airborne dusts are discussed in a booklet by Gelman Instrument Co., Chelsea, Michigan, U.S.A.

**Micro switches.** Fourteen different series of micro switches are represented in a four-page, illustrated pamphlet by Honeywell Controls Ltd., Ruislip Road East, Greenford, Middle-

sex. Each switch has been designed for a particular purpose and each series includes many variations—sizes, weights, contact arrangements, electrical characteristics, housings, actuators, sealing, temperature, shock and mechanical characteristics.

**Silicone rubbers.** Midland Silicones Ltd., 68 Knightsbridge, London, S.W.1, have published a technical booklet describing cold-curing silicone rubbers. These rubbers, made in three grades, need no heat cure; the addition of a small quantity of catalyst converts them at room temperature into heat-stable rubbery products. No special equipment or skill is needed.

### Comical Engineering Corner



"WHENEVER I PRESS THIS ONE THAT HAPPENS"



## TECHNOLOGY NOTEBOOK

### Heavy organic chemicals

The Society of Chemical Industry has formed a new subject group, the Heavy Organic Chemicals Group, which will be inaugurated at a meeting to be held in the Society's rooms at 14 Belgrave Square, London, S.W.1, on November 12. The first officers of the new group are: Dr. R. Holroyd (chairman), Dr. M. A. Matthews (deputy chairman) and Mr. H. P. Hodge (honorary secretary).

The inaugural lecture, by Mr. D. G. Smith, will have the title, 'The Production of Bulk Organic Chemicals,' and will be given at 6 p.m. on November 12.

### Training services in industry

What some employers' organisations and joint bodies are doing in the way of providing training services for the benefit of the firms in their industries is described in a booklet entitled 'Training Services in Industry,' published by the Industrial Training Council, 36 Smith Square, London, S.W.1, price 1s. 6d.

### Expanded polystyrene

The main technical committee of the British Plastics Federation, following a request by members, has recently set up a sub-committee to prepare specifications for expanded polystyrene products. The sub-committee is considering, in the first instance, a specification for 'expanded polystyrene board for thermal insulation purposes.'

### 'Dragon' project

Three engineers, one from Switzerland and two from Italy, arrived in Britain recently as the advance guard of some 90 European engineers and scientists who, with 160 from the United Kingdom, will comprise the international staff of the O.E.E.C. Dragon project at the Atomic Energy Establishment, Winfrith, Dorset. The aim of this project is to develop and build an experimental version of the high-temperature gas-cooled reactor.

£ s d

### CHEMICAL PLANT COSTS

Cost indices for the month of August 1959 are as follows:

Plant Construction Index: 178.3

Equipment Cost Index: 165.3

(June 1949 = 100)

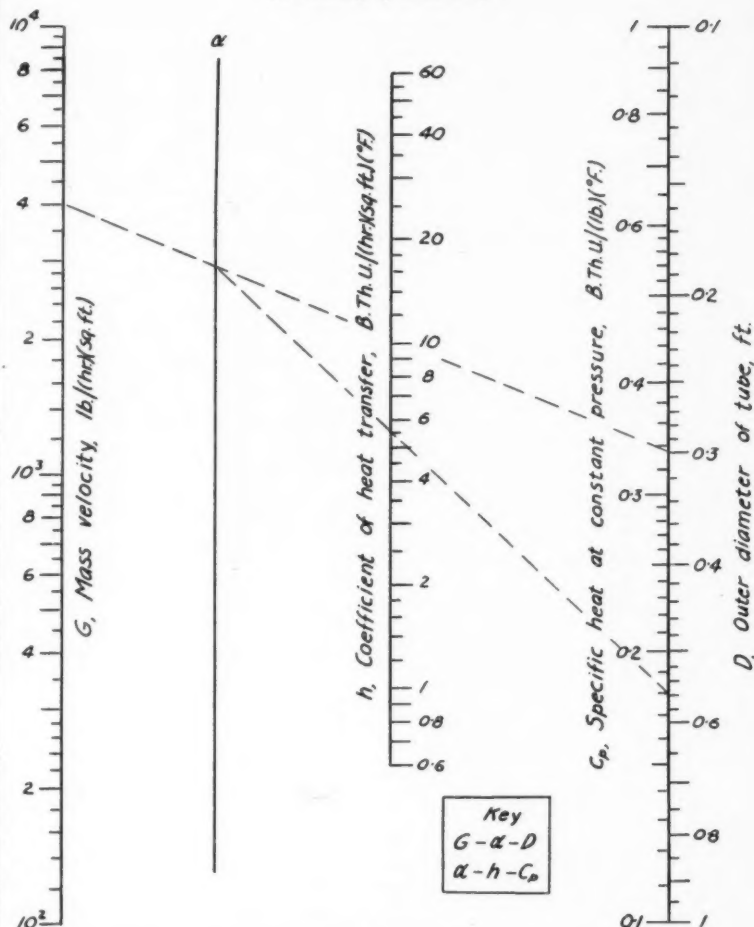
£ s d

## NOMOGRAM

# Heating and Cooling of Gases Flowing Normal to Staggered Tubes

By D. S. Davis

(University of Alabama)



The accompanying nomogram replaces an earlier one<sup>1</sup> in which mass velocities were too low to ensure Reynolds numbers in the range of turbulent flow. The nomogram covers the heating and cooling of gases flowing normal to a 10-row bank of staggered tubes, and is based on the equation

$$h = 0.133 c_p G^{0.6} / D^{0.4}$$

given by McAdams,<sup>2</sup> where  $h$  = heat transfer coefficient, B.Th.U./(hr.)(sq.ft.)(°F.);  $c_p$  = specific heat of gas at constant pressure, B.Th.U./(lb.)(°F.);  $G$  = mass velocity of the gas, lb./(hr.)(sq.ft.);  $D$  = outer diameter of the

tubes, ft.

The broken index lines on the chart show that the heat transfer coefficient for gases flowing normal to a 10-row bank of staggered tubes is 5.5 B.Th.U./(hr.)(sq.ft.)(°F.) when the mass velocity is 4,000 lb./(hr.)(sq.ft.), the outer diameter of the tubes is 0.300 ft. and the specific heat of the gases is 0.180 B.Th.U./(lb.)(°F.).

### REFERENCES

- <sup>1</sup>D. S. Davis, CHEMICAL & PROCESS ENGINEERING, 1959, 40 (4), 145.
- <sup>2</sup>W. H. McAdams, 'Heat Transmission,' 3rd edition, p. 275. McGraw-Hill Book Co. Inc., New York, 1954.

# Company News

Imperial Chemical Industries Ltd. and Société Belge de l'Azote et des Produits Chimiques du Marly (S.B.A.) of Liège, Belgium, recently concluded an agreement under which S.B.A. grants to I.C.I. the licence of its process for ammonium nitrate granulation.

This process is applied by S.B.A. in its own plants and is also used in other units erected abroad for other companies by the S.B.A. engineering division.

An agreement has been signed in Warsaw between Imperial Chemical Industries Ltd. and the Polish foreign trade enterprises, 'Polimex' and 'Textilimport.' The agreement covers the purchase by 'Polimex' of production know-how and a licence to enable a plant for polyester fibre to be built in Poland, and the purchase by 'Textilimport' of polyester fibre which I.C.I. will supply to Poland during the years 1960-64.

It is foreseen that the plant producing the Polish polyester fibre, under the name of *Elana*, will be started up in 1963.

Aluminium Union Ltd. has changed its name to Alcan (U.K.) Ltd. The company is the United Kingdom distributing company for the aluminium ingot and magnesium, bauxite and chemicals produced by its associated companies in Aluminium Ltd. of Canada.

A major capital expenditure programme will expand considerably the glass-fibre output of Glass Yarns & Deeside Fabrics Ltd., an associate company of Microcell Ltd. A large new factory at Camberley, Surrey, includes a battery of furnaces from which fibre drawing will begin shortly.

Keelavite Hydraulics Ltd. have appointed Holman Bros. (Pty.) Ltd. as their agent for the sale of hydraulic equipment in South Africa and Rhodesia. Holman Bros. are manufacturing hydraulic cylinders under licence from Keelavite.

The three companies of Bush Beach & Gent Ltd., Frank Segner & Co. Ltd., and F. S. Bayley, Clanahan & Co. Ltd. have merged to form one company under the title of Bush Beach & Segner Bayley Ltd. The new company will operate not only as a supplier of heavy, fine and pharmaceutical chemicals, but

also as a technical advisory organisation affording assistance on their uses and applications.

The trading activities of the Power-Gas Corporation Ltd. will be taken over by two wholly owned subsidiaries of the same address.

Ashmore, Benson, Pease & Co. Ltd. (directors: W. R. Brown, chairman; C. E. Wrangham, vice-chairman; T. K. Hargreaves, managing director; C. Robson, D. M. R. Brown and R. P. Key) will control the Stockton works, manufacturing and selling all types of heavy engineering products, and specialising in the design and supply of plant and equipment for the iron and steel industry.

P. G. Engineering Ltd. (directors: W. R. Brown, chairman; C. E.

Wrangham, vice-chairman; R. W. Rutherford, managing director; P. M. K. Embling, general manager; C. Robson, C. Ingman and T. H. Riley) will undertake the design and supply of plant and equipment to the chemical, gas and petroleum industries, and also engineering contracts of a general character.

Clarke-Built Ltd. have been appointed the exclusive distributors in the United Kingdom and the Republic of Ireland for the products of the Cherry-Burrell Corporation, U.S.A. Equipment which Clarke-Built will now be offering includes the *Load-automatic* load cell (which gives information on the contents of large liquid tanks) the *Steller* series of *Superhomo* homogenisers, and other products.

## ORDERS AND CONTRACTS

Plant and equipment for the classification of ores, electrolytic tinning, and sintering, are involved in orders recently received by subsidiaries of Head Wrightson & Co. Ltd. Three classifiers, valued at £19,163, are to be installed at a copper mine in Haiti for Denver Equipment Co. This equipment will be supplied by Head Wrightson Stockton Forge Ltd. to handle 500 short tons day of copper ore.

The Head Wrightson Machine Co. Ltd. has been awarded contracts for plant valued at over £2 million for the installation of an electrolytic tinning line at the Ebbw Vale works of Richard Thomas & Baldwins Ltd., capable of tinning and recoiling 1,500 ft. min. of steel strip. Additionally, equipment is being supplied for the preparation of steel strip before it is processed in the tinning line, for the tinplate cup-up lines and for equipment to inspect and assort the plate.

An additional sintering plant is to be supplied by Head Wrightson Iron & Steel Works Engineering Ltd. to the Aviles works of Empresa Nacional Siderurgica S.A., the Spanish national steel company. The new plant is designed to produce an additional 10,000 tons/week of blast-furnace sinter. The total value of the equipment to be supplied is approximately £500,000.

William Boby & Co. Ltd. are supplying two complete demineralisation plants for Mexican power stations. One is for installation at a new power station in Oaxaca which is being built by Associated Electrical Industries Export Ltd. for the Comision Federal de Electricidad Juchitan. Boby are also supplying acid dosing plant for condenser cooling water.

## The Leonard Hill Technical Group—October

Articles appearing in some of our associate journals this month include:

**Manufacturing Chemist**—Perfumery and Cosmetic Raw Materials; Perfumery and Essential Oils; Cosmetic and Toilet Preparations; Pest Control Chemicals.

**Petroleum**—I.C.I.'s New Olefine Plant; Petrochemicals from Belayim Coking Unit; Butadiene Production Using Dow Catalyst; Flares in Modern Refinery Practice; Air Pollution and the Petroleum Industry.

**Paint Manufacture**—Printing Ink Progress; P.A.T.R.A. Printing Ink Research; An Evaluation of Zirconium Driers.

**Automation Progress**—Control and Instrumentation of a Synthetic Rubber Plant; Europe Shows its machine Tools; Magnetic Tape Units for Computing; Applications of Magnetostriction.

**Fibres and Plastics**—Flammability of Fabrics; Tyrex—A New High-strength Yarn for Tyre Cords; Planned Fire Protection.

**Dairy Engineering**—High-temperature Treatment of Milk; Control of Cheesemaking by Physical Methods; The Modern Method of Milk Handling.

**Corrosion Technology**—The Permanent Anode in Impressed Current Cathodic Protection Systems, 1; The Hot-dip Galvanized Coating and Corrosion Resistance, 2; Partly-wetted Galvanic Corrosion Couples; New Paints Systems for Hot-dip Galvanized Steel.

**World Crops**—The Machine in Tropical Agriculture, 2; Subsoiling.

**Food Manufacture**—Machinery for the Jam Maker; Spontaneous Heating of Fish Meal.

# WHAT'S NEW



## Plant • Equipment • Materials • Processes

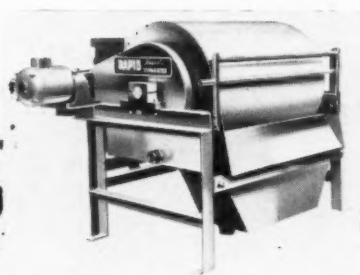
CPE reference numbers are appended to all items appearing in these pages to make it easy for readers to obtain quickly, and free of charge, full details of any equipment, machinery, materials, processes, etc., in which they are interested. Simply fill in the top postcard attached, giving the appropriate reference number(s), and post it.

### Magnetic separator

A permanent - magnet, wet - drum separator for heavy media recovery processes has been introduced by Rapid Magnetic Machines Ltd. Elimination of the densifier demands a magnetic concentrate with a specific gravity of at least 2.2 when using magnetite and the desirability of treating the effluent from the wash screens directly without pre-thickening makes it imperative that maximum magnetite recovery be achieved even when treating very dilute slurries.

The separator incorporates a slimes overflow weir and adjustable orifice rings in the tailings outlet to eliminate the need for valves. Special attention has been paid to the header box which ensures proper presentation of the feed to the drum and eliminates overloading under severe surge conditions.

The 30-in.-diam. drum, provided with expendable, stainless-steel outer covers and available in widths up to 72 in. is energised by a powerful multi-polar *Alcomax* permanent magnet unit, eliminating all electrical wiring and accessories except those



Separator with slimes overflow weir.

necessary for the drive motor. Single-stage recovery at 80 imp. gal. min. ft. of magnet is exceptionally high under a very wide range of feed concentrations, a typical figure quoted from an actual installation being 99.6% recovery at 1.38% magnetite in feed (by weight). This represents a magnetite consumption of less than a tenth of a pound per ton of coal washed, based on an average of 150 gal. wash water per ton of coal. A clean magnetite concentrate of specific gravity 2.4 is produced, independent of feed concentration.

**CPE 1347**

### Robot chemist

The *AutoAnalyzer*, now to be manufactured in the United Kingdom by Technicon Instruments Ltd., is a system for continuous automatic chemical analysis which can detect trace materials down to parts per billion with an accuracy of 1%. By automating each step of a chemical analysis now performed manually (*i.e.* measuring, mixing, purifying, processing, comparing and recording) and integrating them into a continuous flow system, the *AutoAnalyzer* is capable in the laboratory of running 20, 40 or 60 tests/hr. without human supervision. In the plant, it can be connected up to the process or waste stream liquid or gas. The concentration level of any

material or number of materials can be continuously monitored and permanently recorded. If desired, the control loop can be closed to automatically monitor the steady-state control devices or otherwise regulate the process through on-stream continuous measurement.

**CPE 1348**

Fill in and post the reply-paid card for details of any items in these pages, making sure to quote the correct 'CPE' reference number.

### High-efficiency dust collection

A miniature cyclone, the D.584 *Mancuna-Dustex* collector, provides for the same order of efficiency as the earlier D.450 but permits a higher gas volume per cyclone tube with a reduced pressure resistance.

The collector comprises a number of standard cyclone tubes cast with a  $\frac{1}{16}$ -in. wall thickness and available in stainless steel, aluminium alloy, or in an unannealed malleable white iron with a very hard working surface and exceptional resistance to abrasion.

A high recovery efficiency on fine particle dusts is claimed. In addition, cyclone tubes are located in the clean air stream which maintains the tubes at system temperature and prevents condensation and any subsequent tendency to build up and blocking. Suppliers are Mancuna Engineering Ltd.

**CPE 1349**

### Change-over valve

A new change-over control valve designed for use with oil coolers in a turbo-generator provides two opening and closing actions with one movement of the control wheel. The valve has been designed and manufactured by R. Blackett Charlton & Co. Ltd., following a request by C. A. Parsons & Co. Ltd. The turbo-generator installed by Parsons at Oji in Nigeria required a valve which would ensure beyond doubt that the second stand-by oil cooler would come into operation before the one in service was shut off. This means that there can be no risk of damage to the turbo-generator by both coolers inadvertently being shut off at the same time.

The new control valve has eight wedge gates in four valves all operated by one control wheel and shaft, actuating a rack and pinion in each valve. As the four wedges controlling the supply of water and oil to the first cooler are being closed, the four



opposite wedges are simultaneously opening. There is no time lag in the operation and, therefore, no danger to the turbo-generator.

A special spring adjustment mechanism is incorporated in each valve to ensure that the wedges open and close fully.

The body of the valves for both oil and water are all cast iron while the wedges on the water side are of stainless steel, and gunmetal on the oil side.

Although the valve was designed for a particular application, it is claimed to be suitable for use in a wide range of operations involving cooling circuits.

**CPE 1350**

### For manoeuvring materials

A bin of high-density polythene mounted on a pull-along trolley which can be swivelled round on its own axis to negotiate the most awkward spaces has been introduced by Tool Treatments (Chemicals) Ltd. as a useful means of handling a wide range of commodities within factories. The container measures 18 in.  $\times$  15 in.  $\times$  13½ in. and is ideally suitable as a carrier for chemicals and corrosive materials or other products that can be easily



'Mini-Bogie' handling unit.

contaminated. Being stackable the bin is also suitable for storage and is available separately.

The handle of the *Mini-Bogie* can be used fully extended or can be retracted in its container for pushing. The transporter unit is priced at £4 18s. 6d. and the HN.826 container at £3 15s.

**CPE 1351**

### Radioactivity monitor

For monitoring radioactive contamination on benches, clothing, etc., a new instrument is available with all-transistor circuitry, enabling it to be operated for long periods from a battery supply. Produced by E.M.I. Electronics Ltd., the instrument uses a dual phosphor technique which enables  $\alpha$  and  $\beta$  contamination to be monitored simultaneously. They are distinguished by high- or low-pitched

tones conveyed through headphones or through a built-in loudspeaker.

The new monitor is claimed to provide high accuracy over a temperature range of 0 to 45°C. and, by using a single switch, it is possible to monitor the sum of  $\alpha$  and  $\beta$ ,  $\beta$  alone, or just  $\alpha$  contamination. This information, in counts/sec., is displayed on a meter covering 0 to 5,000.

**CPE 1352**

### Cyclones

Neldco Processes Ltd. have been appointed Sterling Area agents for Krebs cyclones. These cyclones have a long-sweep, involuted-feed entry which, in terms of relative performance, increases capacity 25% beyond

its cylinder diameter rating. It is claimed that this type of entry produces a flow pattern which ensures that short-circuiting, with its resultant inaccuracies, is eliminated.

**CPE 1353**

### Large ovens

Large-capacity ovens with external fan and heater units in a range offered by Hedin Ltd. have bodies constructed of standard insulating panels comprising welded angle- or channel-iron frame, lined with heavy-gauge mild-steel sheet and filled with glass-wool insulation. These panels are bolted together to form the walls and roof and are designed to carry the fan, heater unit and duct work. The oven is fitted with hinged double doors or

a vertical lifting door.

Removable *Inconel*-sheathed elements are banked and housed in the heater battery, which is protected against overheating by an excess temperature control. Several heater units are provided, each with a separate fan and individual temperature control. The control gear is housed in a separate control box.

The supply ducts branch out at floor level. Exhaust ducting at roof

level carries the air back to the fan inlet. Adjustable slides in the duct work ensure uniform airflow and even temperature distribution and damper control can be fitted to allow partial or complete circulation of fresh air. The total variation throughout the oven is normally  $\pm 2\%$  of the working temperature, but closer control can be obtained.

**CPE 1354**

### Fine-control stirrer

In a new, variable-speed stirrer offered by Anderman & Co. Ltd., the volts on the armature are controlled by an *Autotransformer* with multiple tapings, whilst the field windings are supplied with a constant high voltage. The advantage claimed for this arrangement is that it gives a range of very stable speeds, with high torque at low speeds, and has the 'fineness of control' that can be obtained with a rheostat, but without the consequent loss of torque at low speeds.

**CPE 1355**

### Lifting and shifting

*Dempster-Dumpster* container-handling vehicles and equipment, for the handling of waste and process materials, are to be made in the U.K. and Europe by Powell Duffryn Engineering Co. Ltd. Dempster equipment is mounted on standard commercial road vehicles and the range consists of vehicles in four series with containers in a great variety of types and sizes.

In the 'L.F.W.' series of seven models, vehicles will lift, transport and dump loads of from 6,000 to 50,000 lb. in various containers ranging from 1 to 15 cu. yd. capacity. Pick-up is by means of chain slings attached to the container by hand; otherwise all operations are effected from the driver's cab.

The 'G.R.D.' will handle any containers of the same size and capacity, with a maximum lift of 9,000 lb., to a dumping height of 10 ft. clearance,



Oven with hinged double doors.



Pull-out pH meter for industrial control panel.

and is suitable for loading into rail wagons, or other road vehicles. Pick-up, dumping and replacement of the container is carried out by the driver without leaving the cab.

The *Dumpmaster* series have bodies of 18, 24 and 30 cu. yd. capacity with hydraulic compaction of up to 3 to 1, and will self-load from containers of 1 to 6 cu. yd., picking up automatically and lifting net loads of up to 6,000 lb./container.

The *Dinosaur* hydraulically picks up or puts down on ground, on wharf, on lorry or on flat rail car, its own body loaded or empty. Body sizes range from 10 to 40 cu. yd. in a variety of designs according to intended use.

**CPE 1356**

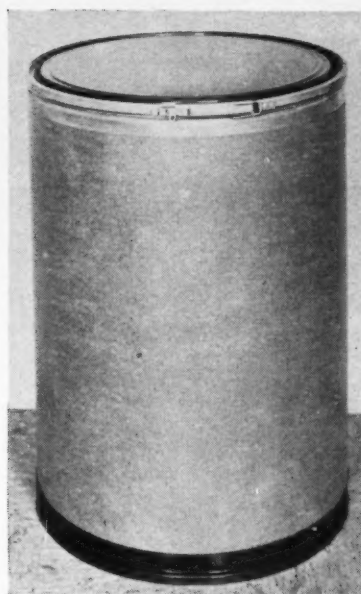
### Miniature pH meter

A miniature version of their industrial pH meter has been produced by Electronic Instruments Ltd. It occupies 60% less panel area and may be used in conjunction with any of the conventional miniaturised recorders or controllers. Its performance is identical to that of the standard instrument and servicing may be carried out by simply opening the glass-fronted door and withdrawing the entire chassis.

**CPE 1357**

### Strengthened drum

The strength of steel and the lightness of kraft are combined in a new



Steel and kraft drum.

drum by Metal Containers Ltd., designed for the carriage of powders, pastes and heavy viscous products. The kraft walls, convolutely wound, enable a wide variety of laminates to be inserted if desired.

The open top is strengthened by a steel chimb and steel lid is sealed by a practical easy-to-fit closing ring. The combined bottom and skirt surrounding vase of body gives protection to the contents even though the drum is stored on wet surface.

**CPE 1358**

## ★ American Developments in Brief ★

Compact purge flowmeters for measuring and controlling liquids and gases at low rates, from Schutte & Koerting Co., are suitable for front-of-panel mounting or for mounting directly in pipelines. They come in nine flow ranges, all obtained in the same basic body through the use of interchangeable glass metering tubes and glass or stainless-steel floats.

**CPE 1359**

The new *Dynamitron* high-power electron accelerator is useful for irradiation of thin plastic films, coatings on wire, synthetic textile fibres, gaseous and liquid chemical reactions, rubber sheeting, and many other industrial products. Model EA-K500 provides a half-million-volt electron with a  $7\frac{1}{2}$ -Kw. output at constant potential. The output at 100% efficiency will process 6,000 megarad lb./hr. Scan widths up to 36 in. are available. Makers: Radiation Dynamics Inc.

**CPE 1360**

Thermal Instrument Co.'s electric flowmeter model 59 uses the thermal conductivity bridge principle to measure and control flows as low as 5 cu.cm./min. of hydrogen or equivalent. It provides a d.c. output signal to actuate any standard indicating, recording and/or controlling instru-

ment. Applications include control of catalyst carrier streams, control of additives, control of chromatographic column gas flow rates, measurement and control of fuel flow rates, and measurement and control in bench scale plants or plant operation.

**CPE 1361**

Highly successful results have been achieved by the use of C2, a sodium chlorite product, to control slime in paper mills, according to the chemicals division of Olin Mathieson Chemical Corporation. They claim that this product is one of the most effective slime killers available for acidic white water systems. Its slimicidal action is based upon the slow release of chlorine dioxide which is generated continuously throughout the entire white water system.

**CPE 1362**

Apparatus for recording dust or gas concentrations, available from Gelman Instrument Co., will automatically collect up to 900 dust or gas samples by sucking air through a paper tape. The volume of air per sample is adjustable from 1.5 to 36 cu. ft. For dust measurements, the darkening of the  $\frac{1}{8}$ -in. diameter sampling spot is measured with a densitometer.

**CPE 1363**

# TUFNOL

## RESISTS CORROSION



Here is a material that is resistant to most forms of corrosion. It is giving excellent service immersed in seawater, mild acids and alkalies, petrol and oil and it withstands constant exposure to extreme climatic conditions. Furthermore, Tufnol is used in various ways to prevent corrosion by electrolytic action. How can Tufnol help you?

Ask our engineer to come and talk Tufnol with you.

STRONG BUT LIGHT  
RESISTS CORROSION  
WITHSTANDS CLIMATIC EXTREMES  
GOOD ELECTRICAL INSULATOR  
MACHINES EASILY  
CAN BE STORED INDEFINITELY

# TUFNOL

(Regd. Trade Mark)

Available in sheets, tubes, rods, angles and channels and in several brands



TUFNOL LTD · PERRY BARR · BIRMINGHAM 22B



# World News

## ITALY

### Petrochemicals

Montecatini recently laid the cornerstone of its big new petrochemical plant at Brindisi which will be one of the biggest in Europe. It will cover an area of 1,235 acres, and its petroleum derivative production will touch 700,000 tons p.a. It will handle an annual 13 million tons of raw materials. The plant will produce plastics, including *Moplen*, polythene, polymers for synthetic fibres, aldehydes, alcohols and organic solvents.

Montecatini already has six petrochemical plants in operation, the largest being those of Ferrara, Novara and Terni.

## BELGIUM

### Oil-fired 'Texaco' plant

Designed and engineered by the Power-Gas Corporation Ltd., England, a *Texaco* heavy oil gasification unit and high-pressure CO conversion plant commenced operation earlier this year at the factory of Société Carbochimique S.A., Tertre. The plant contains two gas generators each to produce crude synthesis gas for 100 metric tons/day of ammonia. Both units have been commissioned and single-unit operation is now at 110% of design rating.

Sulphur is removed before the conversion plant which is provided with a heat-exchange system to make the plant self-supporting in steam when operating with a CO content of less than 2% in the converted gas.

## SWEDEN

### Atomic power project

Atomkraftkonsortiet (AKK), a combine of eight large Swedish private and municipal power producers, are planning to have an atomic power plant operative by 1965, according to Stockholm press reports. In the first stage it would have a reactor of 50 to 60 Mw. Work is scheduled to commence next year. The plant will be located at Simsvarp on the Baltic coast. The reactor proper is likely to be of foreign design since tenders have been invited both from Britain and the United States. However, no final decision as to the type has yet been taken, it is announced.

The reactor would be built under licence in Sweden while the fuel would be supplied by the foreign firm. It is estimated that 70 to 80% of the plant can be built with locally manufactured

components. Total costs are estimated at a minimum of Kr. 100 million (£6.9 million).

The Simsvarp reactor is likely to become Sweden's first industrial power-producing atomic plant, since the State Power Board's R4/*Eva* project, previously planned to go into operation in the mid-1960s, has been delayed. The R3/*Adam* plant, which will become operative in 1963, is primarily intended for district heating of the Stockholm suburb Farsta and will only supply a minor amount of electric energy.

## NETHERLANDS

### Chemicals from natural gas

The Nederlandse Staatsgasbedrijf and the Koninklijke Nederlandsche Hoogovens en Staalfabrieken N.V., IJmuiden, have concluded an agreement relating to the supply of about 200,000 cu.m. of natural gas per 24 hr. for a number of years. This natural gas, which is derived from wells in the west of Holland, will be conveyed to IJmuiden via a pipeline about 80 km. long. It will chiefly be used by the N.V. Maatschappij tot Exploitatie van Kooksovergassen ('Mekog') N.V. in an installation which is to be built for the production of nitrogenous

fertilisers. This installation will be brought into use by the end of 1960.

This will be the first occasion on which natural gas is used in Holland as a basic material for the chemical industry.

In addition to its use by 'Mekog' it will be possible to employ this natural gas as fuel in the manufacture of iron and steel. It will also be possible to use the natural gas as a stop-gap during any breakdown in the public supply of gas by the Hoogovens which provide some 200 million cu.m. p.a. of town gas.

## DOMINICAN REPUBLIC

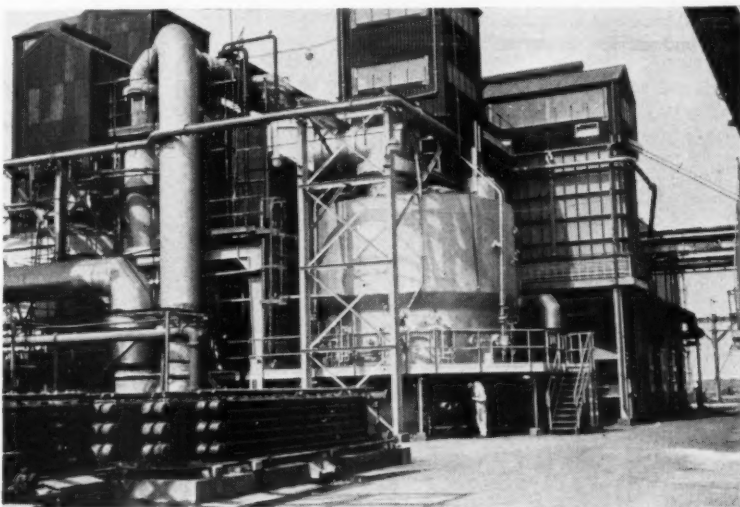
### Nuclear research plans

The Dominican Republic is seeking advice from the Atoms for Peace Organisation on a projected nuclear research programme which would involve the buying of a nuclear reactor for the production of radioactive isotopes for medicine and agriculture. The reactor would also be used for teaching purposes. The announcement was made by Alfredo Vorshirm, head of the Dominican delegation to the Third General Assembly of the organisation in Vienna.

## AUSTRALIA

### Tasmanian aluminium plant

The Governments of Australia and Tasmania have announced agreement upon a plan to increase the capacity



### FERROUS SULPHATE DECOMPOSITION

Chemical Construction (G.B.) Ltd. and Dorr-Oliver Ltd. have recently commissioned this plant, producing SO<sub>2</sub> gas for sulphuric acid manufacture using by-product ferrous sulphate, at the Grimsby works of British Titan Products Co. Ltd.

Dried ferrous sulphate is decomposed with coal in fluidised-bed roasters. The plant was designed and built by Chemico using Dorr-Oliver 'FluoSolid' reactors. The product SO<sub>2</sub> gas is converted to SO<sub>3</sub> for sulphuric acid production in one of the existing converters on the plants supplied by Chemico.

of the Bell Bay aluminium works from 12,000 to 16,000 tons of aluminium ingots p.a. at a cost of approximately £A3 million. The plan for expansion was recommended to the two Governments by the Australian Aluminium Production Commission.

When the enlargement is completed, Bell Bay will be able to supply about half the Australian demand, leaving the remainder to be met by imports.

#### U.S.S.R.

##### Atomic power station

Two units with a total capacity of 200,000 kw. are now under construction at the Beloyarsk atomic power

station in the Urals. The station will have a uranium-graphite reactor of a type similar to that of the first Soviet atomic power station but with improved technical features. It will also be more economical to run.

It will use slightly enriched uranium as fuel. Graphite will be used both as moderator and reflector. The graphite lattice will be 29 ft. high and nearly 31½ ft. in diameter. It will be enclosed in a metal shell surrounded by a layer of water 3½ ft. thick.

The station's efficiency is rated at 33.8%. It is scheduled to begin supplying current to the Urals power grid in 1961.

ments were also made by Kemper and Zimmerman to determine the temperature range for recovery of the damage in the *Zircaloy 2*. The irradiated specimens were annealed at temperatures in the range 250 to 400°C. for 10 and 100 hr. respectively. No appreciable recovery or reduction in damage due to thermal annealing alone occurred in *Zircaloy 2* until temperatures greater than 300°C. were produced. The recovery process was rapid in the range 350 to 400°C. and approximately 90% of the yield strength increase was removed in 100 hr. at 375 and 400°C. The activation energy for the process at 50% recovery was 49,200 cal./mole which is of the order of that reported for self-diffusion in zirconium.

#### REFERENCES

(References 1 to 21 appeared with Part 1 of the article)

- <sup>22</sup>W. G. O'Driscoll, C. Tyzack and T. Raine, *Int. Conf. Peaceful Uses Atomic Energy*, Geneva, 1958, Paper No. 1450.
- <sup>23</sup>S. Kass, 'Zirconium—Technology and Economics,' *Atomic Industrial Forum Inc.*, Nov. 1955, p. 39.
- <sup>24</sup>D. E. Thomas and F. Forscher, *J. of Metals*, 1956, 8 (5), 640.
- <sup>25</sup>L. S. Rubenstein, *Nucleonics*, 1959, 17 (3), 72.
- <sup>26</sup>O. Flint, A.E.R.E. Report M/R 2646, July 1958.
- <sup>27</sup>B. Cox, A.E.R.E. Harwell, private communication.
- <sup>28</sup>R. S. Ambartsumyan *et al.*, *Int. Conf. Peaceful Uses Atomic Energy*, Geneva, 1958, Paper No. 2044.
- <sup>29</sup>J. P. Pemsler, U.S.A.E.C. Report NMI-1208, Aug. 1958.
- <sup>30</sup>A. B. McIntosh and K. Q. Bagley, *J. Inst. Metals*, 1955-56, 84, 251.
- <sup>31</sup>U.S.A.E.C. and Dept. of the Navy, 'Liquid Metals Handbook,' 1952.
- <sup>32</sup>C. Tyzack, *Nucl. Engg.*, 1958, 3 (4), 102.
- <sup>33</sup>W. L. Mudge, 'Zirconium and Zirconium Alloys,' A.S.M. Cleveland, 1953, p. 146.
- <sup>34</sup>W. D. McMullen, U.S.A.E.C. Report WAPD-TM-132, April 1958.
- <sup>35</sup>R. E. Johnson and A. F. Stevens, U.S.A.E.C. Report WAPD-TM-81, Aug. 1957.
- <sup>36</sup>E. T. Hayes and W. W. Stephens, *Metal Progress*, 1953, 63 (5), 97.
- <sup>37</sup>S. R. Maloof, U.S.A.E.C. Report NMI-1205, Aug. 1958.
- <sup>38</sup>F. R. Shober, J. A. Van Echo, L. L. Marsh and J. R. Keeler, U.S.A.E.C. Report BMI-1168, 1957.
- <sup>39</sup>C. Judge and L. Wortley, Admiralty Materials Laboratory, Report No. SA/68(S), July 1955.
- <sup>40</sup>C. Judge and D. Healey, *Ibid.*, A/70(S), Sept. 1956.
- <sup>41</sup>C. Judge, *Ibid.*, private communication.
- <sup>42</sup>R. S. Kemper and W. S. Kelly, U.S.A.E.C. Report HW-38079, July 1955.
- <sup>43</sup>M. J. Makin and F. J. Minter, *J. Inst. Metals*, 1956-57, 85, 397.
- <sup>44</sup>R. S. Kemper and D. L. Zimmerman, U.S.A.E.C. Report HW-52323, Aug. 1957.
- <sup>45</sup>C. Judge, Admiralty Materials Laboratory Report No. A/71(S), May 1957.

## Personal Paragraphs

★ **Mr. F. H. Braybrook**, until recently general manager of Petrochemicals Ltd. (an associate of Shell Chemical Co. Ltd.) has taken up a senior appointment in the group responsible to the director of co-ordination chemicals in Shell International Chemical Co. Ltd.

★ **Mr. P. W. Howard** has relinquished the office of managing director of B.T.R. Industries Ltd., but will remain a director and the deputy chairman of the company. **Dr. W. D. Scott** has been appointed to succeed Mr. Howard as managing director.

★ Carbide Industries Ltd., a member of the British Oxygen group of companies, announce the appointment at their carbide and acetylene factory at Maydown, near Londonderry, of **Dr. T. W. T. Baillie** as production manager, **Mr. W. W. Ringland** as chief works engineer, **Mr. A. R. Robertson** as commercial manager, and **Dr. R. D. Thrower** as works research and development manager.

★ **Mr. R. E. Huffam** has been re-elected for a second term of office as president of the British Standards Institution. He was, until his recent retirement, United Kingdom co-ordinating director of Unilever Ltd. The three deputy-presidents of the Institution, **Sir Roger Duncalfe**, **Sir Herbert Manzoni** (City Engineer of Birmingham) and **Mr. John Ryan** (vice-chairman, Metal Box Co. Ltd.) were also re-elected.

The following members of B.S.I.'s chemical division councils were elected to serve on the General Council: **Mr. S. J. Davies** (managing director, A. Gallenkamp & Co. Ltd.), **Mr. F. Fancutt** (assistant director of research, British Railways) and **Mr. H. W. S. Wright** (Surgical Instruments and

Medical Appliances Industry Standards Committee). **Mr. H. Crawshaw** (British Celanese Ltd.) was amongst those elected from the textile division.

★ **Mr. C. Soukup**, managing director of Richard Klinger Ltd., has retired owing to ill health. He has been associated with the company for nearly 50 years. His retirement coincides with the birth of a new venture in Australia (see 'Company News' last month) where he has planned a unit, now nearing completion, for the manufacture of *Klingerit* high-pressure jointing. Mr. Soukup's son, **Mr. R. Soukup**, is a very active member of the board and sales manager to the organisation.

★ **Maj. W. R. Brown** has now relinquished the post of joint managing director of the Power-Gas Corporation Ltd., but continues as chairman of the board. **Mr. C. E. Wrangham** is now sole managing director of the company and continues as vice-chairman of the board. (An announcement about a change in the organisation of the Power-Gas Corporation's trading activities is included in 'Company News' this month.)

## Technology of Zirconium and its Alloys

(Concluded from page 368)

integrated thermal neutron exposure of  $1.4 \times 10^{21} \text{ n cm}^{-2}$ . The results are summarised in Table 17. The change in yield stress of the cold-worked material is nearly as great as for the annealed material. A yield point with a slight drop in load was developed in the annealed and irradiated specimen.

Post-irradiation annealing experi-

